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Technical Report 527

HIGH TORQUE-TO-INERTIA SERVO SYSTEM FOR STABILIZING SENSOR SYSTEMS

CANDIDATE SYSTEMS INCLUDE MISSILE GUIDANCE, SURVEILLANCE, AND TRACKING

FD Groutage
Avionics Systems Branch
Code 7311

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Final Report

Prepared for
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This is a technical report on the design and development of a high torque-to-inertia servo system for stabilizing a sensor system. The design philosophy leads to a low cost/high performance system. The stabilizing element developed is universal and has application for 1) missile guidance, 2) surveillance, and 3) tracking sensor systems The servo design is based on math models and is used to develop performance specifications and perform evaluations.

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OBJECTIVE

Establish the design and develop a servo system for space stabilizing and command positioning a sensor system. Provide growth potential in the design for alternate sensors or sensor weight to be added to the gimbal structure without servo system performance degradation.

RESULTS

1. A high torque-to-inertia servo system for space stabilizing a gimballed sensor was developed. The high torque-to-inertia concept led to a low-cost design configuration with multisensor growth potential which would allow additional weight to be affixed to the gimbal structure.

2. Math model designs were formulated for the sensor system/stabilization platform in time- and frequency- domains.

3. A system control interface was developed to test and monitor the servo system in both the stabilization and slave command modes.

4. Performance levels were established for the stabilization and the slave command modes of operation.

RECOMMENDATION

Review some of the gimbal mechanical designs for minimizing friction.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

1. INTRODUCTION

This report covers the design and development of a universal servo system for space stabilizing a sensor system for tracking applications.

1.1 BACKGROUND ON SPACE STABILIZED SENSORS FOR MISSILE GUIDANCE

Space stabilized sensors for missile guidance are used for the following reasons:

(1) They provide an inertial reference from which the line of sight rate can be measured.

(2) Body motion is decoupled from the guidance signals.

(3) The target is tracked (sensor system pointed at the target through a mechanical gimbal system) where the sensor system is maintained boresighted on the target.

Alternate ways of achieving the above characteristics have been derived using "fixed body" (sensor system centerline fixed relative to the missile body centerline) sensor systems. An example of the fixed body sensor is the electronic beam steering sensor by means of phased array antennas. The fixed body systems are rather atypical of tactical missiles and will not be specifically addressed. These beam steering systems are in many ways analogous to the gimballed system as far as the resulting overall missile guidance is concerned.

This report presents in detail the design and development of a space stabilizing sensor system platform. The aspects of how and why gimballed stabilization platforms achieve the above criterion (inertial reference, body motion decoupling, and target tracking) will be expanded upon.

The design philosophy is based on a high torque-to-inertia ratio which is detailed in the "Stabilized Platform Design" section.

The primary emphasis of this report relates to a space stabilization platform used for stabilizing a missile guidance sensor. The platform, however, is not restricted to this application. It is equally well suited to other applications such as stabilizing a sensor for surveillance and data gathering systems. In essence the development presented in this report relates to a state of the art/high technology space stabilizing sensor platform. Many systems, whether they be missile guidance, surveillance, or other type of tracking systems require that the tracking sensor be space-stabilized. This report covers the various phases of the develop ment of a high torque-to-inertia space stabilizing sensor platform with universal respect to a number of applications. Reference 1 presents examples of systems that could utilize stabilized platforms for surveillance sensor or missile guidance systems.

1. Groutage, FD, Strike Drone – A Defense Suppression Concept Using Unmanned Cruise/Loiter Attack Vehicle, SAE Transactions, Vol. 87, 1978.

2. MATH MODEL DEVELOPMENT

A math model for the stabilized platform was developed and from this model design specifications and predicted system performance were established.

2.1 SENSOR MEASUREMENT GEOMETRY

The fundamental function of a space-stabilized sensor is to measure and provide estimates of these measured guidance signals to the missile control section. The fundamental measurement made by the sensor is the angular position of the target relative to the sensor centerline or boresight. The angular information required for missile guidance control is the angular line of sight rate. This assumes that missile guidance is via proportional navigation. Missile guidance control can be structural around a number of different guidance laws, reference 2. The guidance law assumed in this document was proportional navigation.

Figure 1 illustrates the geometry for the sensor/missile/target angular relationships.

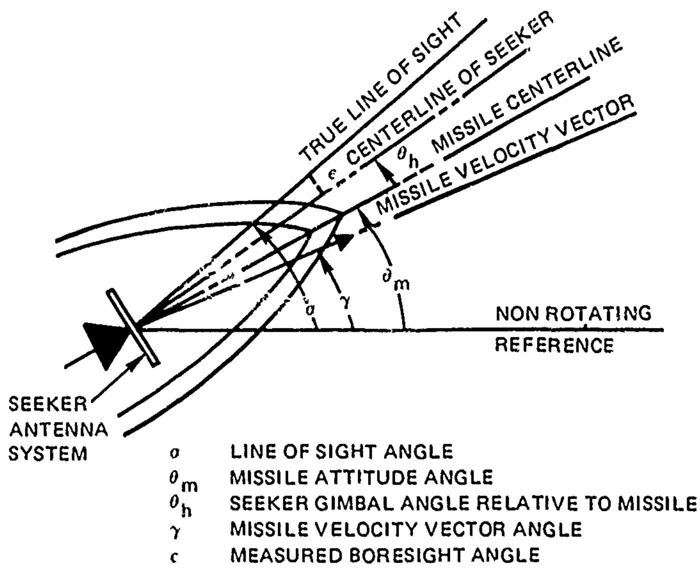


Figure 1. Sensor/missile/target angular relationship.

A block diagram can be generated based on the geometric relationships described in figure 1.

$$\epsilon = [\sigma - \theta_m - \theta_h]\, T_1(s) \qquad (1)$$

where $T_1(s)$ is the sensor transfer function.

2. Paarmann, LD, Faraone, JN, and Smoots, CW, Guidance Law Handbook for Classical Proportional Navigation, ITT Research Institute, GACIAC HB-78-07, 1978.

This equation can be translated to a diagram using two summing junctions as follows:

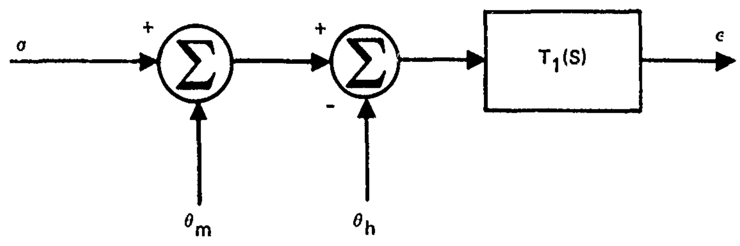


Figure 2. Block diagram of equation 1.

Using rates rather than position quantities, figure 2 is changed as follows:

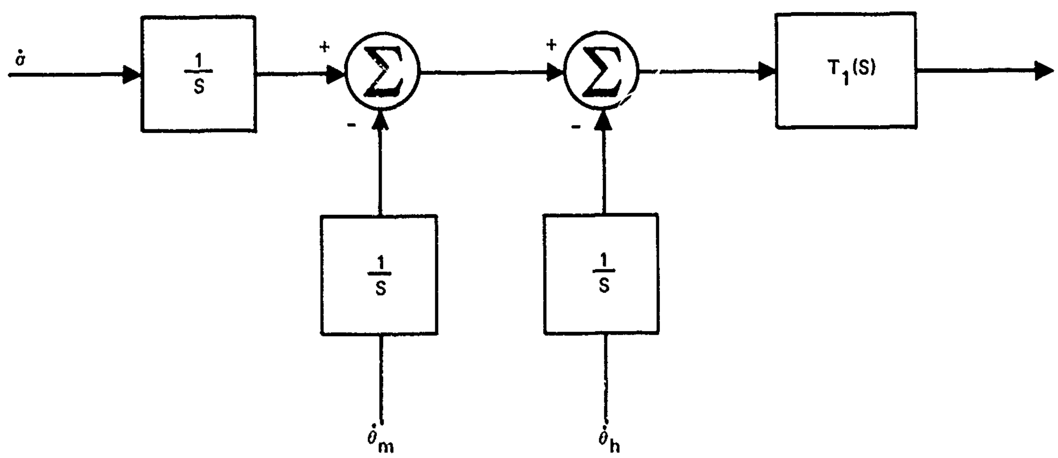


Figure 3. Block diagram of measured boresight error signa (σ̇, $\dot{\theta}_m$ and $\dot{\theta}_h$ are rate quantities).

To be an inertial reference a device must maintain a fixed attitude in space or be space stabilized. Space stabilization is accomplished by means of a rate sensor mounted on the element to be fixed or stabilized in inertial space. Missile body motion or base motion, body rate ($\dot{\theta}_m$) is sensed by the rate sensor which generates an output voltage proportional to the missile body rate. The rate sensor output voltage is used to generate a head rate opposing the missile body rate. The net rate sensor input then becomes the difference between head rate and missile body rate. The purpose of this servo loop is to maintain zero head rate relative to inertial space. The degree to which stabilization can be achieved is determined by the loop gain. For stability, a compensation/shaping network is included in the loop which maintains a required phase/gain margin.

Incorporating the elements of the stabilization loop into a block diagram relative to the geometry of figure 1 is illustrated in figure 4.

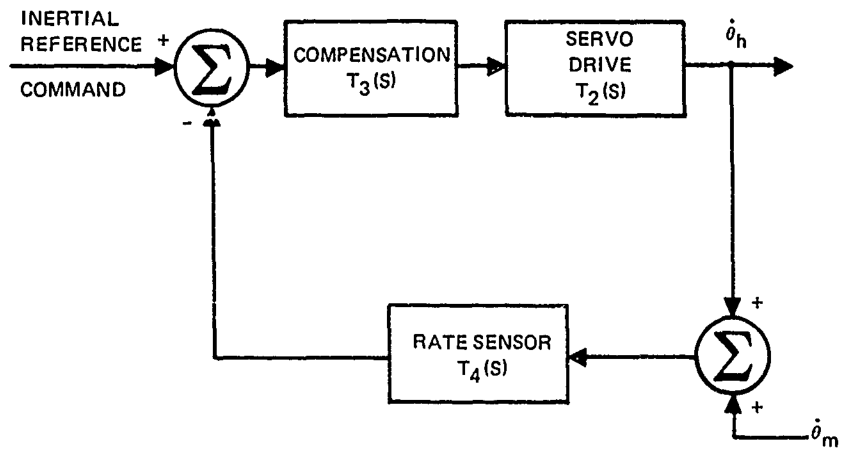


Figure 4. Stabilization loop.

Figures 3 and 4 are combined relative to the geometry of figure 1 which results in stabilized tracking sensor system which is shown in figure 5

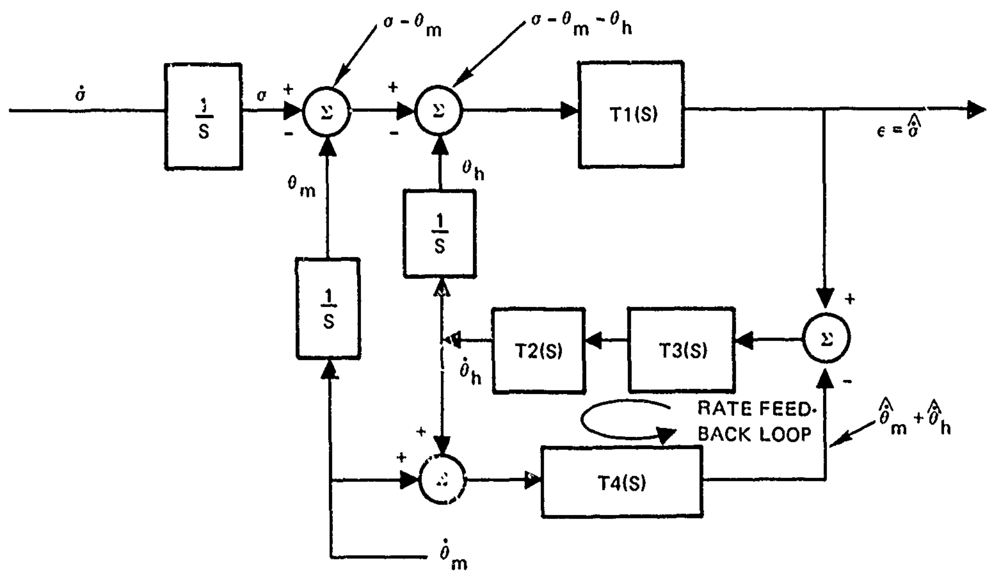


Figure 5. Sensor tracker system.

The following definitions hold for the transfer functions and variables in figure 5:

$T_1(s)$ is Sensor Transfer function

*$T_2(s)$ is Torque Source – Servo Drive/Load Inertia transfer function

$T_3(s)$ is the electronic servo gain and compensation networks Transfer functions

$T_4(s)$ is the Transfer function of the rate Sensor which is physically mounted to the gimbal structure.

$\epsilon = \hat{\dot{\sigma}}$ is the measured Line of Sight (LOS) rate or the estimated LOS rate.

$\hat{\dot{\theta}}_m$ is the measured value of the missile body angular rate in a particular plane.

$\hat{\dot{\theta}}_h$ is the measured value of the Sensor gimbal angular rate in a particular plane.

Figure 5 is the starting point for the design, development and analysis of a space-stabilized sensor system.

2.2 MATH MODEL

Figure 5 was formulated based on sensor/missile/target angular relationships. Figure 5 can be reconfigured as shown in figure 6.

*Usually consists of torque motor, torque motor servo amplifier, and load, which includes gears, gimbals and sensor load inertia.

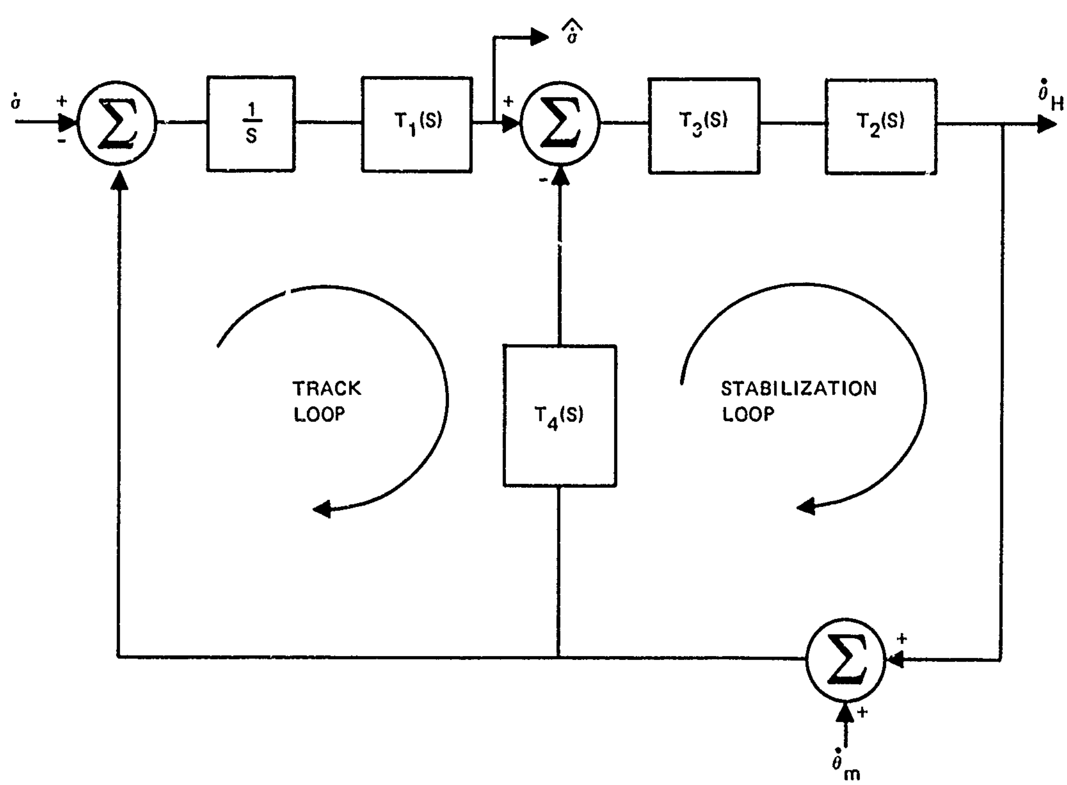


Figure 6. Generalized block diagram of sensor/stabilized platform.

$T_4(s)$ has the units of volts/rad/sec.

$T_1(s)$ has the units of volts/radian.

$T_3(s)$ has the units of volts/volt.

$T_2(s)$ has the units of rad./sec./volt.

The stabilization and the track loops are the fundamental servo loops that are designed together since they are the heart of the stabilized platform system. The slave loop is independent of the track loop and can be designed separately. Therefore, two models must be developed:

1. Stabilization/Track, and
2. Slave loop models.

The stabilization loop provides the body motion decoupling properties that were mentioned earlier as a desired requirement of the space stabilized platform. The stabilization loop, also referred to as the stab loop, is drawn separately as illustrated in figure 7.

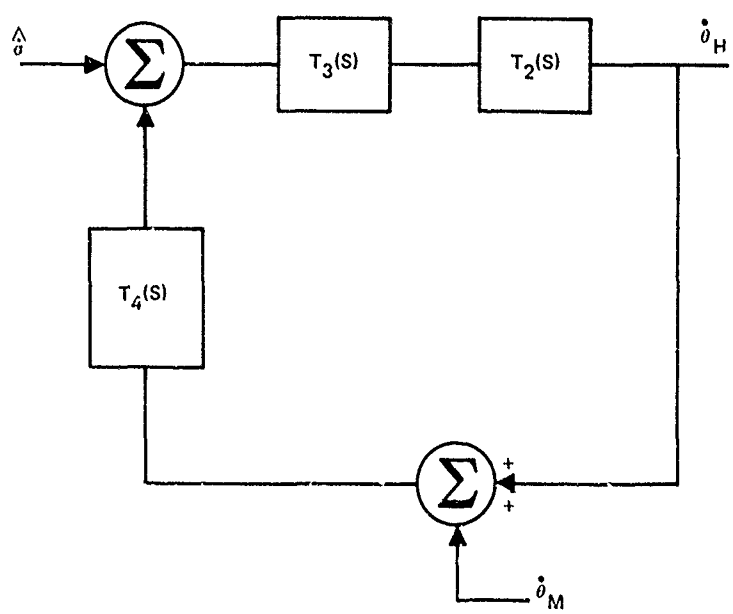


Figure 7. Generalized block diagram of stabilization loop.

The transfer function of the gimbal movement ($\dot{\theta}_h$) as a function of steering commands ($\hat{\sigma}$) is as follows:

$$\frac{\dot{\theta}_h}{\hat{\sigma}} = \frac{T_3(s)\, T_2(s)}{1 + T_3(s)\, T_4(s)\, T_2(s)} \tag{3}$$

where the assumption is made that $\dot{\theta}_m$ is zero.

The transfer function of the gimbal movement ($\dot{\theta}_h$) as a function of body motion inputs is as follows:

$$\frac{\dot{\theta}_h}{\dot{\theta}_m} = \frac{-\,T_4(s)\, T_3(s)\, T_2(s)}{1 + T_4(s)\, T_3(s)\, T_2(s)} \tag{4}$$

It is easily seen that for the magnitude of $T_2(s)\, T_3(s)\, T_4(s)$ large or

$$|T_2(s)\, T_3(s)\, T_4(s)| \gg 1 \tag{5}$$

that

$$\theta_h \approx -\theta_m$$

This illustrates the body motion decoupling principle of a space stabilized platform. Another way of looking at the body motion decoupling properties of the space-stabilized platform is to examine figure 5. Body motion decoupling implies that the platform subtracts out the motion caused by missile body movement, θ_m, from the desired estimated line of sight guidance signal, $\hat{\sigma}$. Figure 5 is reconfigured as shown in figure 8.

By applying the condition of equation (5) to the transfer function block where body motion feeds into the platform loop, the block diagram illustrated in figure 8 can be simplified as shown in figure 9.

Note that the body motion term $\dot{\theta}_m$ cancels itself out of the steering command, $\hat{\sigma}$. In section 4.0 a detailed analysis and data are presented on the level of body motion that is contained (or corrupts) the desired missile steering command ($\hat{\sigma}$). Of course it is immediately obvious that the desired situation is as modeled in figure 8. There is no corruption of the steering command; however, this is not achievable in reality. Some level of body motion will corrupt the missile guidance steering command. It is this level of corruption that is expanded upon in section 4.0.

2.2.1 Torque Source Model – $T_2(s)$

The torque source and type of configuration are the basic determinations that must be made to quantify the gimbal drive element or the blocks that make up the $T_2(s)$ transfer function of figure 5. Actually the torque source is only one element of the $T_S(s)$ transfer function. $T_2(s)$ is the overall transfer function of the servo amplifier, torque source and gimbal/load. The torque source was selected as an electrical dc, armature controlled torque motor. Other alternatives could have been hydraulics, pneumatics, or electrical motor/clutch drive systems. For the particular guidance sensor environment, torque requirements

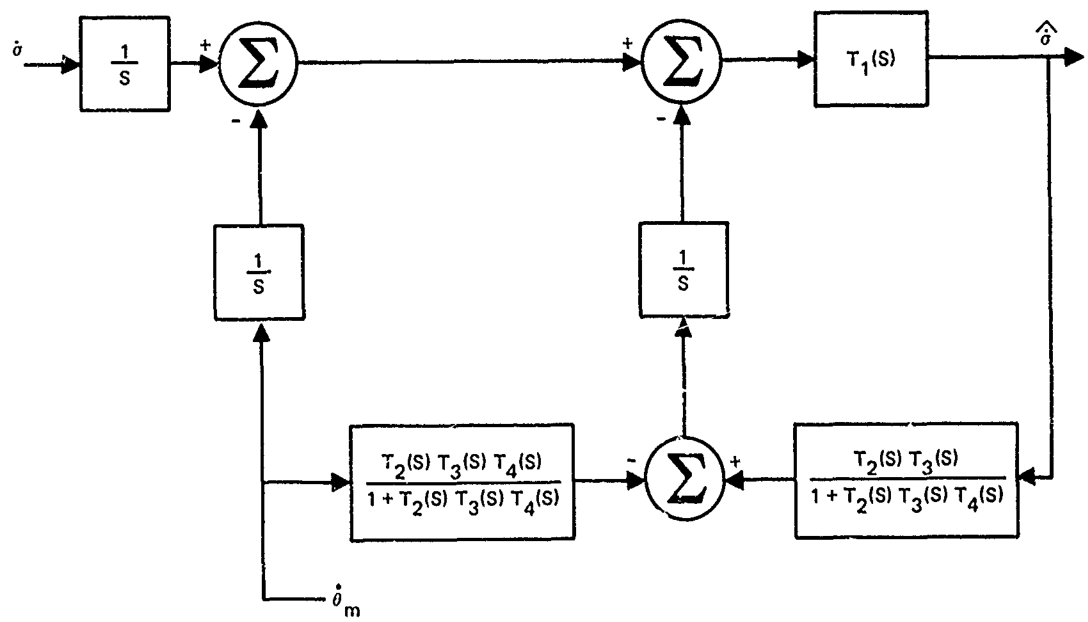


Figure 8. Block diagram of stabilized platform.

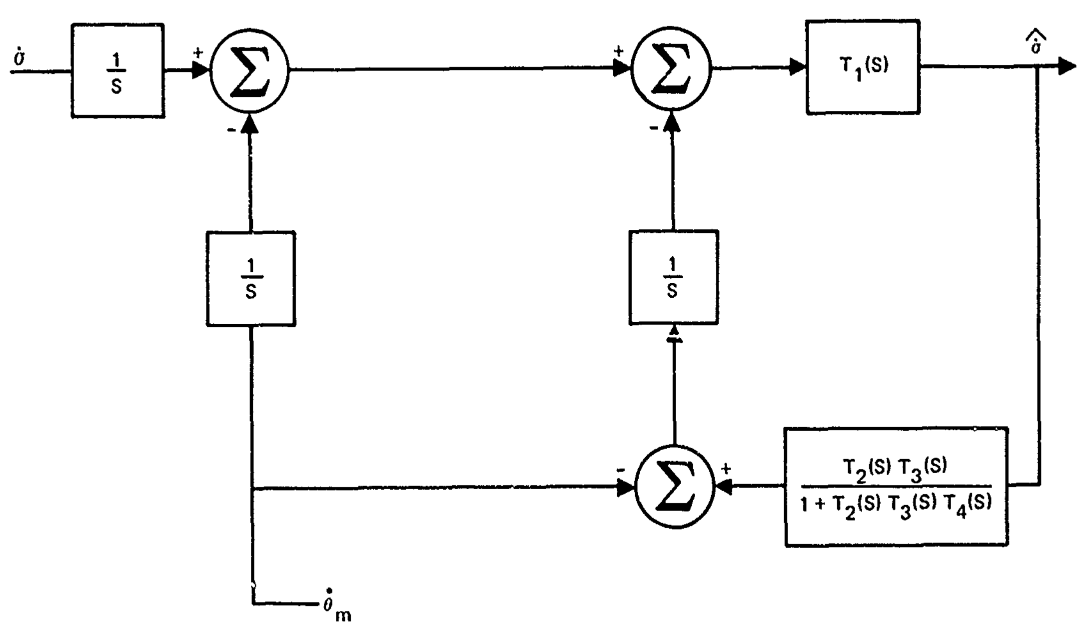


Figure 9. Simplified block diagram of stabilized platform.

and packaging constraints the dc armature controlled torque motor approach was selected. Once this selection was made the configurations as to the control of the torque source needed to be determined.

Basically there are two choices of drive control, voltage, or current. The parameters for relating the control (voltage or current drive) are: (1) system response, (2) velocity error constant, and (3) isolation to extraneous signals and torque sources. A model for each of the control drives is illustrated in figures 10 and 11 (10 is the Current Drive and 11 is the voltage drive servo control). Derivation of each of these models are presented in Appendix C.

In figure 11, the voltage control configuration, it is noted that the servo amplifier is outside the feedback path of the servo motor as compared to the configuration of figure 10, the current control servo drive system. The servo motor and the load for the system of figure 11 is relatively independent of the servo amplifier. The servo amplifier gain is strictly an electronic gain. Therefore, in a response comparison between the voltage drive and the current drive systems, the voltage drive system would consist of the motor/load elements while the current drive system would include the servo amplifier characteristics. Figure 12 shows a simplified block diagram of the servo drive and the electronic gain/compensation elements of a servo system.

For a comparison the transfer function V_R/V_C must be evaluated for both types of drive systems.

The transfer functions for the two different servo drive controls are:

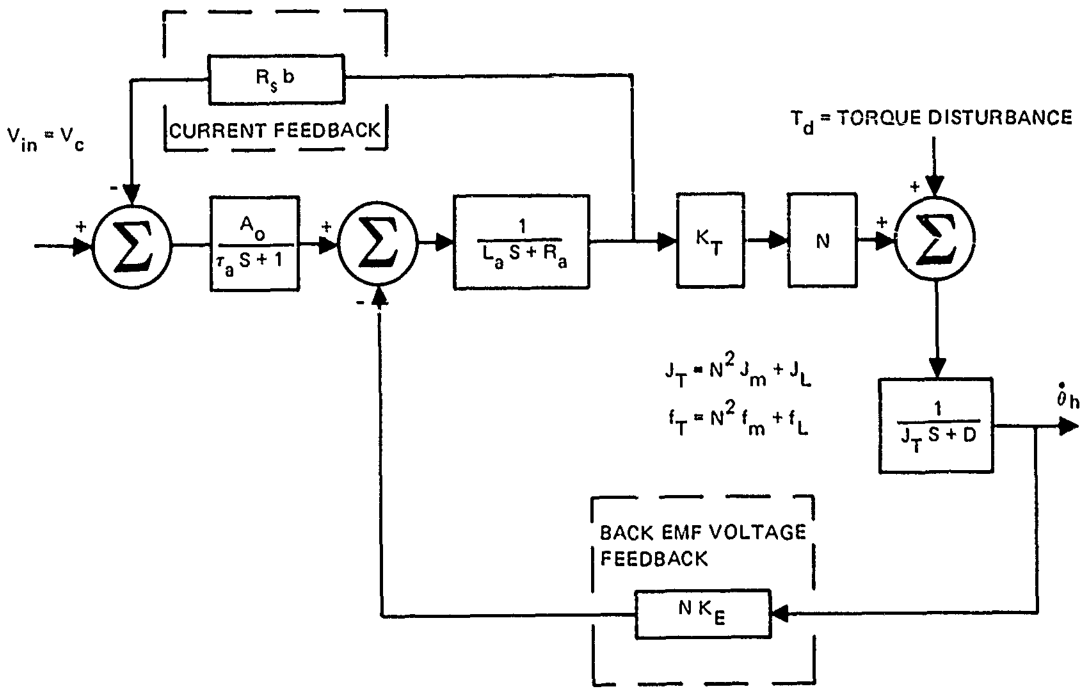
$$T_4(s) = \frac{\dot{\theta}_h}{V_c} = \frac{A_o K_T N}{L_a J_t \tau_a S^3 + (L_a \tau_a D + \tau_a J_t R_a + L_a J_t) S^2 + (DL_a + \tau_a D R_a + J_t R_a + A_o R_{sb} J_t + K_T K_E N^2 \tau_a) S + R_a D + A_o R_{sb} D + N^2 K_E K_T} \tag{6}$$

for current drive, and

$$T_4(s) = \frac{\dot{\theta}_h}{V_c} = \frac{A_{CL} K_T N}{L_a J_t S^2 + (J_t R_a + DL_a) S + R_a D + N^2 K_T K_E} \tag{7}$$

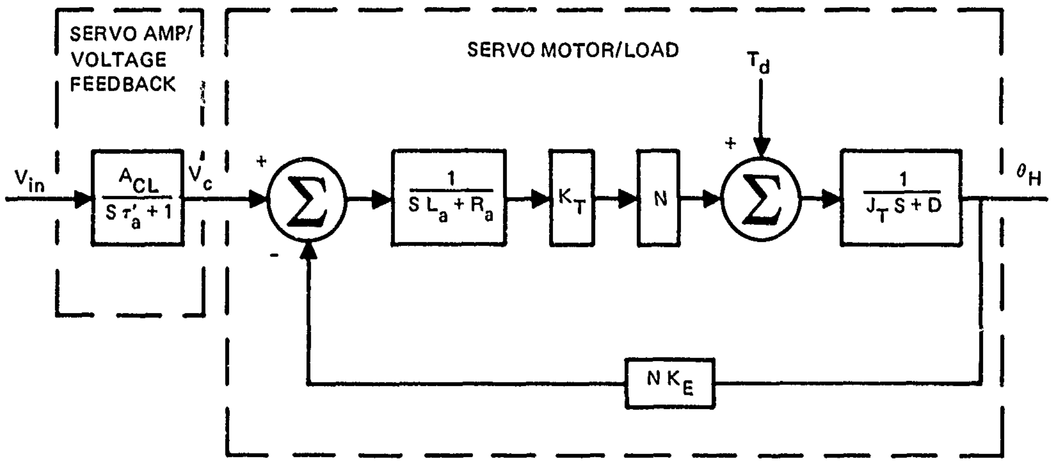
for voltage drive.

The above equations (6 and 7) can be analyzed using inverse La Place transform theory. That is, the corresponding time responses for each type of system can be evaluated for identical inputs. A time domain analysis using an integration routine on the computer can also be used to evaluate the time domain response of the servo drive systems. The La Place transform technique does not take into consideration the nonlinearities of the system while the time integration procedure does. Both of these analysis techniques as well as the computer programs are contained in Appendix E. The current drive system is a third-order system (due to amplifier dynamics) and the voltage drive is a second-order system.



A_o = AMPLIFIER OPEN LOOP GAIN
N = GEAR TRAIN RATIO
R_s = CURRENT SENSING RESISTOR
b = CURRENT FEEDBACK GAIN
K_T = MOTOR TORQUE CONSTANT
K_E = BACK EMF VOLTAGE CONSTANT
τ_a = OPEN LOOP AMPLIFIER BREAK POINT
La = ARMATURE INDUCTANCE
R_a = ARMATURE RESISTANCE

Figure 10. Block diagram of current drive servo control.



$A_{CL} \cong \frac{\beta-1}{\beta}$ WHERE β IS THE VOLTAGE FEEDBACK OR RATIO OF THE INPUT (R_1) TO INPUT & FEEDBACK RESISTOR:

$$\tau'_a \cong \frac{\tau_a}{\beta A_o}\left(\frac{R_i}{R_i + R_c}\right)$$

Figure 11. Block diagram of voltage drive servo control.

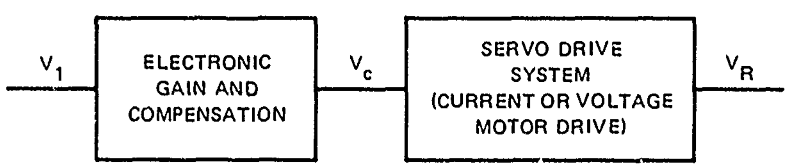


Figure 12. Servo drive system.

The eigen values for each of these systems are evaluated. The location of the roots of these two different types of systems will specify the kind of performance that can be achieved. Specifically, the characteristic roots govern the behavior of the system; therefore, as part of the evaluation criterion to establish which servo control will be used a close look will be taken at where in general the roots lie for these two systems. The transfer functions in expanded form are presented in equations (6) and (7). A typical set of values for a candidate torque motor is as follows:

$Ra \doteq$ armature resistance = 3.0Ω

$La \doteq$ armature inductance = .0014 Henries

$K_T \doteq$ motor torque constant = 24.8 in-oz/amp

$K_E \doteq$ back EMF constant = .177 V/Rad/sec

The driving amplifier (servo amplifier) open loop parameters are:

A_o = open loop gain = 100,000 volt/volt

τ_a = time constant = .02 sec

The parameters that are not specifically known or defined, but are in a relative ball park are the load inertia and viscous damping. Typical values of these parameters are in the following range:

$$.5 \leqslant J_L \leqslant 5.0$$

$$.1 \leqslant D \leqslant 3.0$$

The gear ratio is the parameter that is not fixed. This parameter can be selected to optimize the performance of the servo drive system. The range of values for the gear ratio (for practical considerations) range from direct to gear ratios of around 50.

Appendix E (figures E-6 and E-7) presents a set of data on gear ratio parameter variations to establish the optimum gear ratio.

Returning to equations (6) and (7) with the above values for the parameters it is seen that the low frequency eigen value for the current drive system is very close to zero and the other two roots, which are complex, are far-out roots and do not influence the response in the region of interest. For the outer gimbal the three eigen values are:

$$S = -.159$$

and

$$S = -1.096 \times 10^3 \pm 5.975 \times 10^4$$

The dominant root is the real root at −.159.

The voltage drive configuration has two real roots. The dominant root sets at

$$S = -34.1986$$

with the other root at

$$S = -2108.8168$$

The dominant root for the current drive system is 215 times closer to the origin. This real root near the origin greatly increases the low frequency gain and therefore the velocity error constant of the current drive system as compared to the voltage drive system.

The time response data for each system with a step input is illustrated in figures E-2 and E-3. For the obvious reasons illustrated in these figures the current drive system was chosen as the type of servo drive for the stabilized sensor platform.

2.2.2 Stabilization/Track Loop Models

Basically the derivation of the math model for the stabilization/track loops comes from the generalized block diagram presented in figure 6. The three major elements that make up the stabilization loop are the rate sensor ($T_4(s)$), the torque source/load ($T_2(s)$), and the electronic gain/compensation ($T_3(s)$). The rate sensor is an off-the-shelf item. The specifications of the given rate sensor depends in large upon the specific requirements it must meet for required performance and operating environment. Appendix A presents in detail the definition of the rate sensor, its characteristics/specifications, and rationale for selection.

General specifications for the rate sensor chosen (Honeywell two-axis rate sensor, GG2500) are presented in table 1, and a cutaway view and an outline drawing showing size and configuration are shown in figure 13.

2.2.2.1 Rate Sensor Model – $T_4(s)$. The transfer function for the rate sensor/readout electronics is

$$T_4(s) = \frac{-K_{MHD} K_2}{(\tau_4 S + 1)^3} \tag{8}$$

where K_{MHD} is the rate sensor gain in V_{RMS}/rad/sec. and K_2 is the demodulator gain in V_{DC}/V_{RMS}. The denominator of equation (8) defines a third-order low pass noise filter.

2.2.2.2 Stabilization/Track Loop Compensation Model – $T_3(s)$. A lag-lead type of compensation was chosen to stabilize the servo loop and implement the high acceleration gain and set the bandwidth. The lag portion of the compensation allows a higher low frequency gain to be achieved and thereby a higher acceleration gain. The type of lead compensation chosen provides a minimum phase at a design frequency which sets the closed loop bandwidth. The gain is adjusted so that the zero dB crossover is at the minimum phase location. There is a fair amount of latitude available with this kind of design philosophy. If more loop gain is required for stabilization, isolation properties and acceleration properties, the lag portion of the compensation network can be adjusted. An integrator is incorporated

Parameter	
Scale Factor	GG2500LC02: 15 ± 5% mv rms/deg/sec GG2500LC03: 15 ± 1% mv rms/deg/sec
Zero Rate F.ror (includes run-up repeats)	GG2500LC02: 0.5 deg/sec. max. GG2500LC03: 0.15 deg/sec max.
Linearity	0.1% of max. rate (max dev from best str line)
Cross Coupling (axis change vs. input rate)	0.5% of full scale (max dev from best str line)(1)
Hysteresis	0.01 deg/sec max.
Threshold	0.01 deg/sec max.
Acceleration Sensitivity	0.05 deg/sec/g max.
Output Noise at Null	100 mv rms max. (using 1000-Hz bandwidth meter)
Rate Input Range	± 480 deg/sec
Frequency Response	100 Hz min. without electronics
Ref Gen Output	1V min. rms each axis
Ref Gen Phase Angle	90 ± 0.5 degrees
Performance Stability With Environments	
Zero Rate Error Stability Over All Environments	0.15 deg/sec
Acceleration Sensitivity Stability Over All Environments	0.03 deg/sec/g
Scale Factor Change - vs - Temperature	± 2%
Input Axis Change - vs - Temperature	± 0.5 deg
Excitation Requirements	
Motor	26 ±2 volt rms 400 Hz 2Ø, 4 watts max.
Preamp	± 15 ± 3 Vdc, 4 ma max. with 500 mv max p-p ripple
Environments	
Overrange Capability	20,000 deg/sec
Temperature	-65°F to +160°F
Vibration	MIL-STD-810, Method 514, Proc II 2 hr/axis – time schedule V of Table 514-II, Curve H (10g peak sine) 1/2 hr/axis – time schedule II of Table 514-II, Curve Q (10g peak sine) 1/2 hr/axis – time schedule II of Table 514-II, Curves AH (11.9g rms random) and AK (20.7g rms random)
Shock	2 drops/axis each direction, 12 drops total each level: 40g, 18 ms; 400g, 1.5 ms; 100g, 6 ms; 500g, 0.75 ms; MIL-STD-810, method 516, proc IV
Acceleration	100g, each direction – each axis
Useful Life	Life tested to 1000 hours
Temperature Shock	MIL-STD-810, method 503, proc I + 71°C to -54°C to +71°C, four (4) hours each temp – 5 minutes between chambers

(1)When operated with amplifier-demodulator readout electronics. Deviation is expressed as a percent of opposite axis full scale.

Table 1. MHD rate sensor specifications (GG2500LC02 and GG2500LC03).

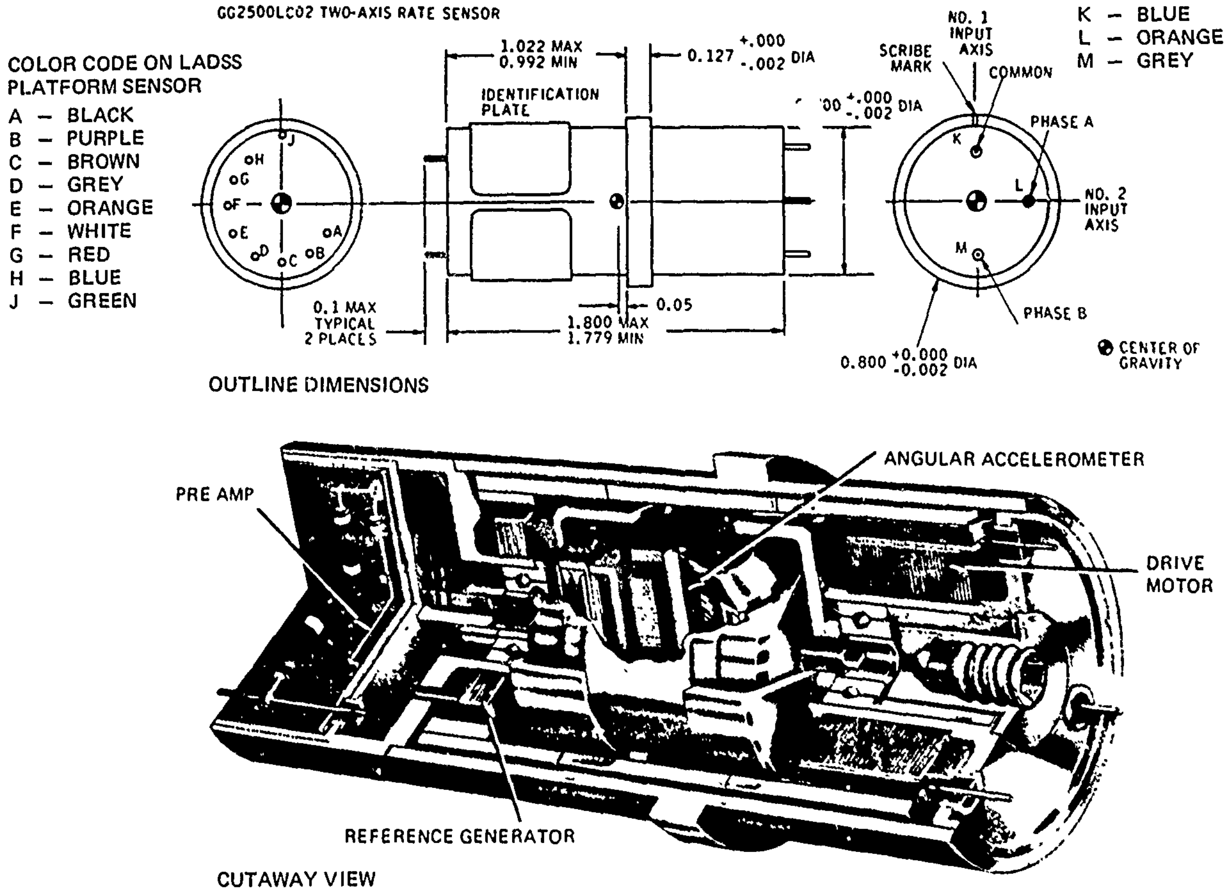


Figure 13. Outline dimensions and cutaway view of rate sensor.

into the compensation network to yield a type one system. References 3, 4, and 5 present compensation techniques for these types of servo system. The compensation transfer function is

$$T_2(s) = \frac{K_3\,(\tau_2 S + 1)\,(\tau_2' S + 1)\,(\tau_5 S + 1)}{S\,(\tau_3 S + 1)\,(\tau_3' S + 1)\,(\tau_6 S + 1)} \tag{9}$$

The lead time constants are τ_2, τ_2', τ_3, and τ_3' where

$$\tau_2, \tau_2' > \tau_3, \tau_3' \tag{10}$$

The lag time constants are τ_5 and τ_6 where $\tau_5 < \tau_6$.

3. Horowitz, IM, Synthesis of Feedback Systems, Academic Press, 1963.
4. Davis, SA, Feedback and Control Systems, Simon and Schuster, Technical Outlines, New York, 1974.
5. Shinners, SM, Modern Control Systems Theory and Applications, Addison-Wesley Publishing Company 1972.

2.2.2.3 **Stabilization/Track Loop Math Model.** The complete math model for the stabilization/track loops model is defined in the block diagram of figure 14. Included in this diagram is the saturation nonlinearities which are due to amplifier saturations of the various amplifiers in the servo amplifier drive system, the compensation network and the rate sensor feedback system. Appendix B presents data on the servo amplifier used in the system. This math model is the basis for the synthesis/design of the stabilized platform track mode. All of the analysis for performance evaluation was accomplished using this model.

A number of items need further exploration. The output of the sensor is the all important estimate of the line-of-sight rate, designated $\hat{\sigma}$. This value is in units of volts, therefore, it is related to the angular values of radians through a scale factor. This scale factor is the product K_2 times K_{MHD}.

The estimated value of the line-of-sight is the quantity that is inputed to the flight control systems of a guided missile. Since this parameter is referenced to a scale factor; that is, a specific voltage equates to a given line-of-sight rate through a linear relationship, and any gains in the loop which are not constant would contribute to an error in the estimate of the line-of-sight rate. Gain variations are caused by a number of different phenomena such as temperature, acceleration bias, nonlinear seeker guidance measurements and radome error slopes. These items are mentioned at this time to point out that total missile performance is a function of the sensor/stabilization platform's ability to generate accurate line-of-sight measurements. The major contributor to the line-of-sight rate degradation relative to the platform design is the effect of acceleration bias on the rate sensor in the feedback loop. The sensor gains and radome error slope degradation to the line-of-sight rate is not a function of the platform design. The track loop model does include the sensor function but this is only for performance evaluations. There are numerous references on the sensor nonlinearity gain and radome error slope degradation of the line-of-sight rate, see references 6 and 7. Since the rate sensor is a major element of the stabilization platform, the effect of acceleration bias and how it affects the estimated line-of-sight rate ($\hat{\sigma}$) will be examined. As an example refer to the data presented in table 1. We find that the acceleration sensitivity of the MHD rate sensors (GG2500LC02 and GG2500LC03) is 0.05 deg/sec/g max. For a 10 "G" acceleration the rate sensor will contribute a 0.5 deg/sec error in the estimated line-of-sight rate. In this example suppose that K_2 = 14 volts Dc/volts rms and that K_{MHD} = 0.8595 volts rms/rad./sec and assume that the platform is moving at a rate of two degrees/sec. The voltage being sent to the flight control system is then 0.4190255 volts. Now if the platform, while moving at a two deg/sec rate is subjected to a 10 "G" acceleration, the voltage being sent to the flight control system will be 0.3149986 volt which is an erroneous input to the autopilot since the estimated line-of-sight rate is actually two degrees/sec, but the autopilot is looking at a 1.5 degree/sec. signal which it takes as the line-of-sight rate.

2.2.3 Slave Loop Model

The slave loop, shown in figure 15, is a position type one servo system. The function of the slave loop is to position the sensor or slave the movement of the sensor to an

6. Naval Electronics Laboratory Center, San Diego, CA, NELC TR 2023, Radome Development for a Broadband RF Missile Sensor, by FD Groutage, 1976.
7. The Analytic Science Corporation, TR-170-4, Performance Evaluation of Homing Guidance Laws for Tactical Missiles, 1973.

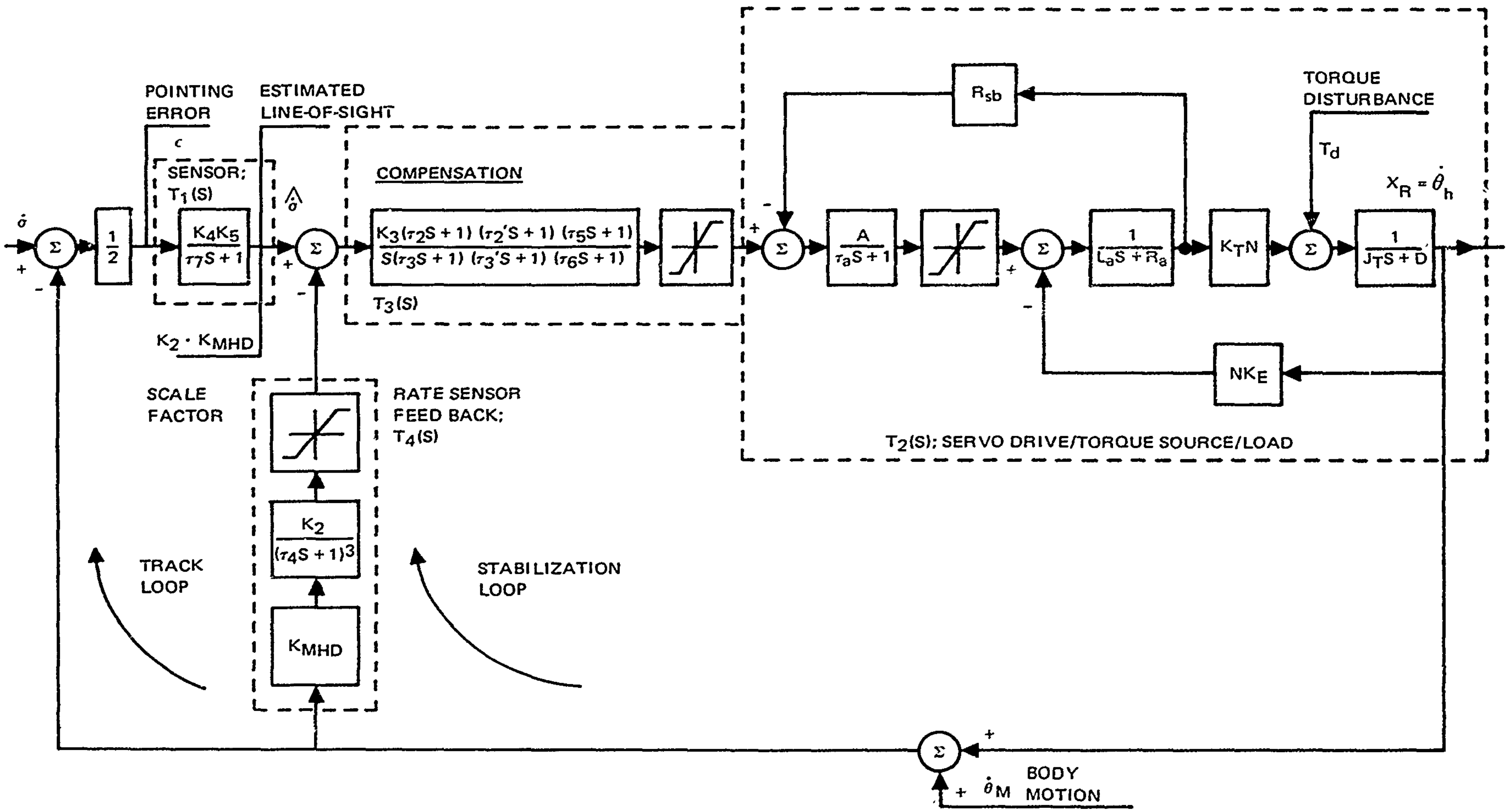


Figure 14. LADSS stabilized platform track/stabilization loops block diagram.

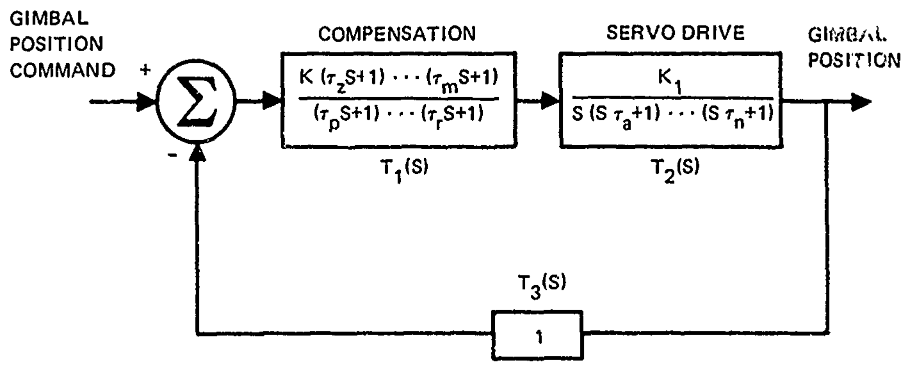


Figure 15. Slave loop representative block diagram.

input command signal. For a position command following type of servo system, the final steady-state position error is a function of the position constant, K_p.

The steady-state error for a type 1 system for a position input is zero.

$$K_p = L(s)|_{s=0} \tag{11}$$

where

$$L(s) = T_1(s)\, T_2(s)\, T_3(s) \tag{12}$$

is the loop transfer function.

JJ D'Azzo, (ref. 8), presents a chapter on basic servo system characteristics relative to the steady-state performance of the system.

2.2.3.1 Slave Loop Compensation. The slave loop compensation block is essentially a lag-lead network. The electronic gain or loop gain adjustment is also contained in this block. This type of compensation allows the gain margin, phase margin, and bandwidth to be specified. Contained within the compensation block is a nonlinearity as a result of the limiting of the electronic amplifier used to synthesize the network. Figure 16 illustrates the model of the compensation network.

2.2.3.2 Slave Loop Math Model. The complete math model of the slave loop is presented in figure 17. This figure represents the elements comprising the position Type 1 servo system. The servo drive/torque source/load element is identical to that shown in figure 14, a block diagram of the track/stabilization loop.

8. D'Azzo, JJ and Hoopis, CH, Feedback Control Systems Analysis and Synthesis, McGraw-Hill Book Company.

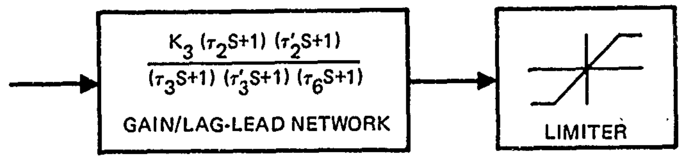


Figure 16. Slave loop compensation network.

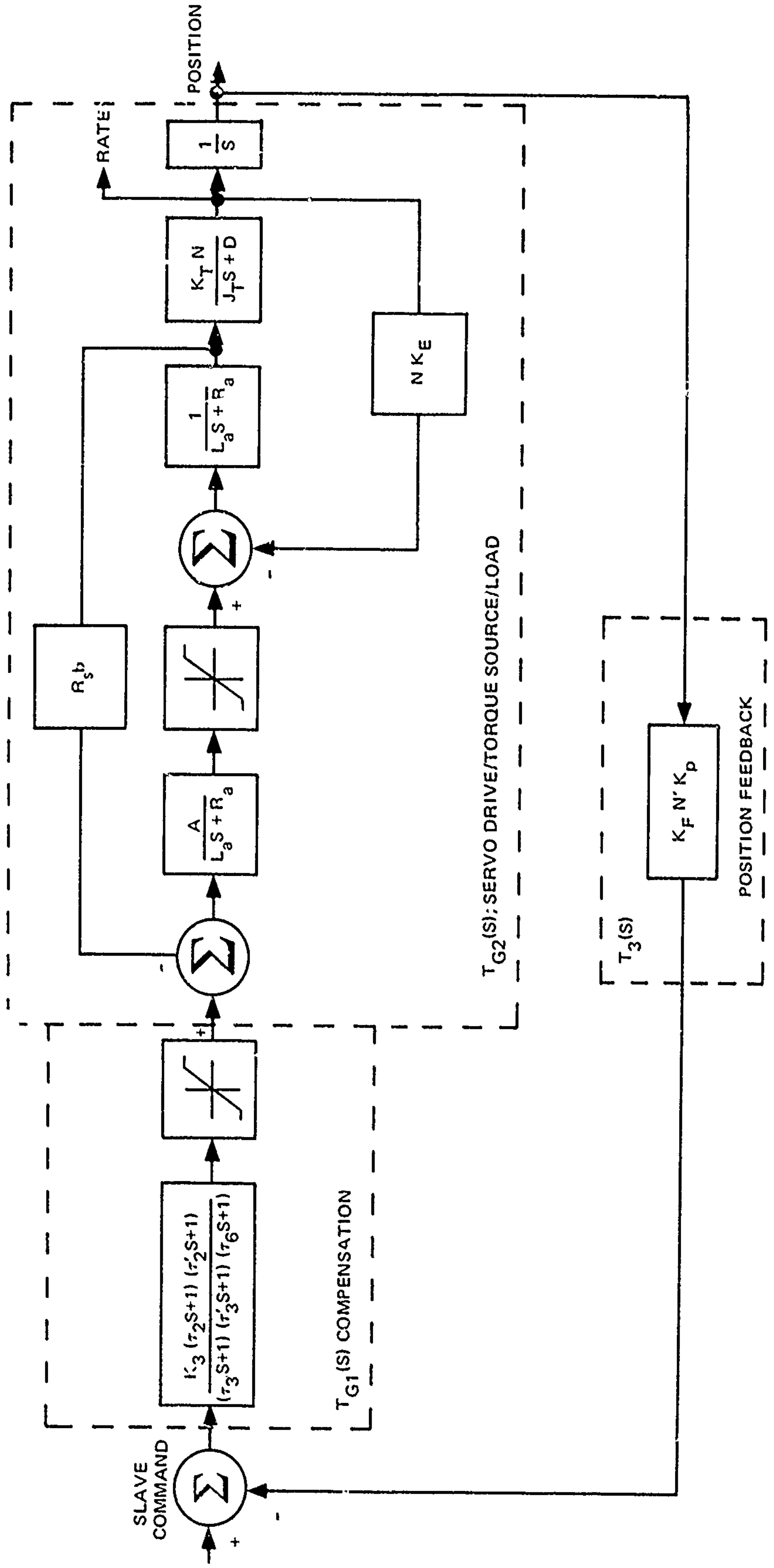


Figure 17. Slave loop of sensor servo platform.

3. STABILIZED PLATFORM DESIGN

3.1 DESIGN PHILOSOPHY

The paramount design criterion was a high torque-to-inertia ratio for the following reasons:

(1) Leads to a low cost design.

(2) Allows growth to multiple sensors on the stable member of the platform.

(3) Achieves high isolation from unwanted inputs such as base or body motion and extraneous torques.

(4) Has high acceleration and high velocity performance.

With the high torque-to-inertia ratio as the basic approach, the design philosophy addressed two major areas: 1) mechanical design, and 2) servomechanism design. The mechanical design addressed the gimbal type and drive arrangement. The servo design addressed the servomechanism performance and specifications for the track/stabilization and slave loops independently. Performance specifications for both the frequency and time domain were established. Once these specifications were established the problem was reduced to that of a synthesis problem or one of formulating a system that will meet the desired performance specifications. This, to say the least, is not an easy problem. There are many approaches to the synthesis problem each of which may lead to a unique solution. In control system engineering problems there are many solutions that could conceivably satisfy a set of performance specifications. It is the synthesis problem and the solution thereof that present the greatest challenges to the control system engineer. It is in this area that creativity and ingenuity applied with basic engineering are the ingredients for the desired solution.

3.2 MECHANICAL DESIGN

A two degree of freedom stabilized platform consists of a set of gimbals such that a member attached to the gimbal set can be positioned about a pivot point (virtual or fixed) in any of a number of positions within the gimbal travel limits. Figure 18 is a simplified representation of two degrees of freedom motion for a member attached at a pivot point on a fixed base. There are a number of ways that the two degrees of freedom of motion can be achieved through various gimbal schemes. Usually these gimbal arrangements are called inner and outer gimbals. Each gimbal has a separate drive source to move the gimbal. It turns out that for an inner/outer gimbal arrangement at least one of the gimbal drive torque sources must be physically displaced with the gimbal movement (for a geared torque drive system). The torque source that moves or is physically displaced when the gimbals move is the inner gimbal drive source. The outer gimbal drive source can be made stationary, ie, it is not physically displaced with gimbal movement. The inner gimbal drive source can be attached to the inner gimbal and thus will be physically displaced when the inner gimbal moves, or it can be attached to the outer gimbal and will only be displaced when the outer gimbal moves. There are advantages to this last arrangement, inner gimbal drive physically attached to outer gimbal. Figure 19 illustrates this concept. The outer gimbal is a semicircle

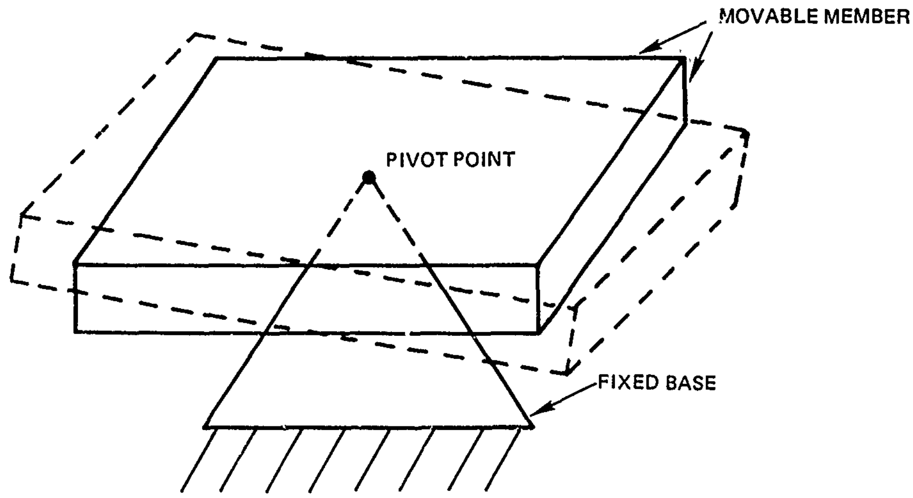


Figure 18. Simplified pivot platform.

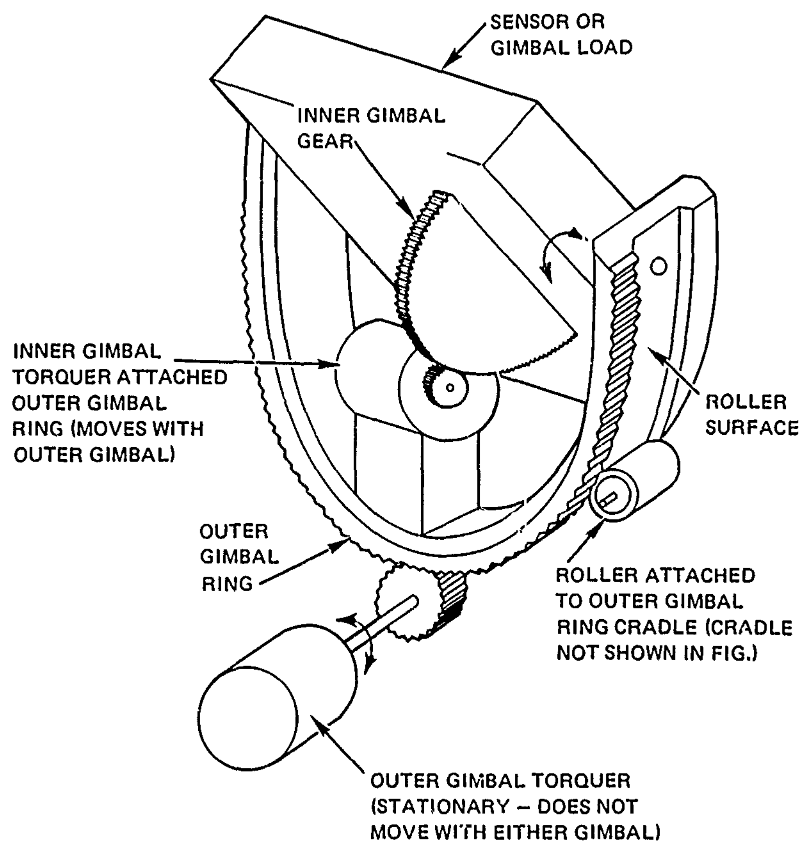


Figure 19. Inner/outer gimbal configuration showing inner gimbal torquer attached onto the outer gimbal.

(bail ring) which is driven, through a gear train, by a fixed stationary torque source. The bail ring choice for an outer gimbal has the following advantages:

(1) It leads to a virtual pivot point which allows the sensor or load to be physically positioned at the pivot point. (In many sensor applications this is extremely important.)

(2) It lends itself to larger/heavier sensor loads because volume within the semicircle can be utilized for sensor packaging.

(3) The sensor/load is physically attached at two points (inner gimbal bearing points) which allows the heavier/stiffer loads and maintains higher mechanical resonances.

The advantages of the inner gimbal drive source being physically attached to the outer gimbal is that the torque source can be made physically much larger yielding a larger inner gimbal torque value. Traditionally the inner gimbal torque source has been physically located on the inner gimbal. With this arrangement movement of the inner gimbal consisted of the load and the torquer. The weight of the torquer adds directly to the inner gimbal inertia and therefore is of prime concern since the driving design parameter is a high torque-to-inertia ratio. With this arrangement (inner gimbal torque source physically located on an inner gimbal) not only are smaller torque values achievable, but the total inner gimbal inertia is increased leading to a smaller torque-to-inertia ratio, rather than a larger torque-to-inertia ratio. In contrast, the design arrangement that places (physically mounts) the inner gimbal torque source on the outer gimbal leads to a high torque-to-inertia design. The inertia of the outer gimbal is increased by the addition of the inner gimbal torquer; however, the outer gimbal torquer is mounted to a reference that does not move with either inner or outer gimbal movement. It can therefore increase in size yielding a larger torque value to drive the outer gimbal with the added weight.

The inner/outer gimbal and torque drive arrangement shown in figure 19 has another paramount advantage - it lends itself to an optimum gearing arrangement. Figure 20 presents a typical curve showing speed of response to gear ratio. It is seen from this figure that a direct drive system is far from optimum. In fact it approaches the same performance as a very high gear ratio system. The semicircle bail ring/inner gimbal drive located on outer gimbal design is of a geometrical shape and configuration such that optimum gearing can be taken advantage of.

3.3 SERVO MECHANISM DESIGN

As mentioned earlier, two separate independent servo loops are used in the sensor platform: 1) Track/stabilization loop used for null tracking a target to generate an estimate of the line-of-sight rate and decouple base or body motion from the estimated line-of-sight rate and provide a space stabilized inertial reference, and 2) Slave loop used to position the sensor or slave the sensor to a commanded position input. Figures 15 and 17 are block diagrams of these two servo loops respectively. Since these two loops are independent, each will be treated as separate designs.

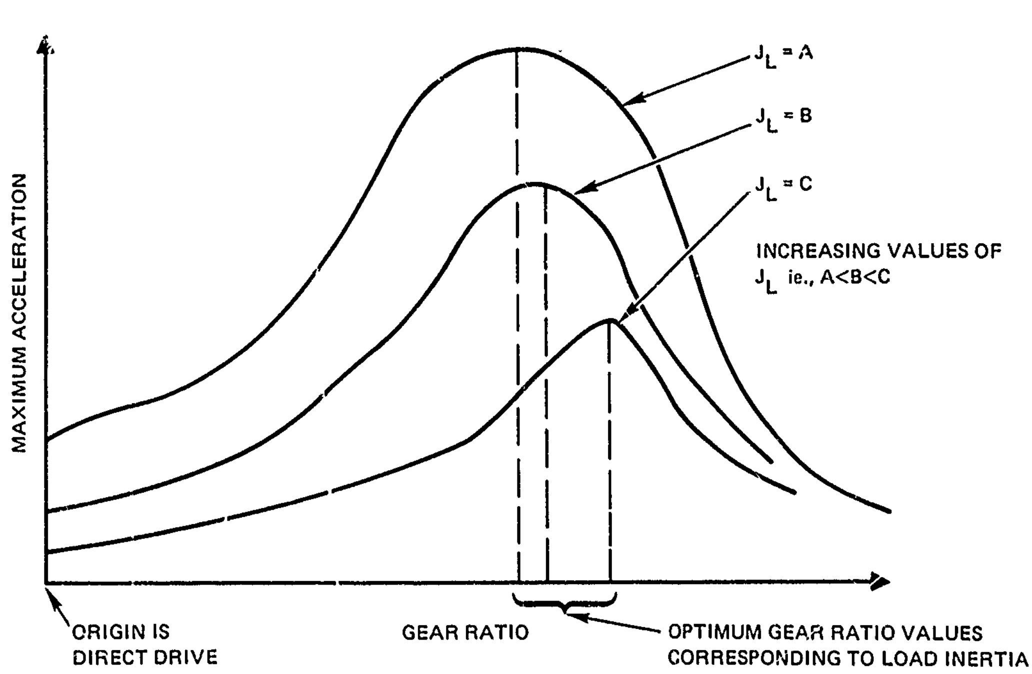


Figure 20. Typical response curve as a function of gear ratio and load inertia.

A. PERFORMANCE SPECIFICATIONS

Performance specifications (ref 9) may be divided into three sub groups:

1. Frequency-domain specifications.
2. Time-domain specifications.
3. Specifications on statistical bases.

The first two are the most popular and dominate the literature. These will be used to establish the design parameters and performance specifications of the servo loops.

B. FREQUENCY-DOMAIN SPECIFICATIONS

Frequency-domain specifications are those which relate to the relationships between the sinusoidal input and outputs of a servo mechanism. A list of the more common frequency-domain specifications found in the control systems literature are:

1. Bandwidth

9. Elgerd, I., Control Systems Theory, McGraw-Hill Book Company, 1967.

2. Phase margin (and crossover frequency)
3. Gain margin
4. M peak (and peak frequency)
5. Deviation ratio
6. Error-constant–bandwidth ratio
7. Output impedance
8. Gain-bandwidth product

Not all of these specifications are mutually exclusive. A more concise list of the frequency-domain performance specifications are

1. Bandwidth BW
2. M peak M_p
3. Peak frequency ω_p
4. Output impedance Z

Figure 21 presents a typical magnitude plot from which the definition of the frequency-domain performance specifications are illustrated.

In figure 21 BW_3 is the three dB bandwidth. This is the servo bandwidth normally referred to as just BW. The BW_6 bandwidth is referred to as the 6 dB bandwidth. $|T(jw)|$ is the magnitude of the total cloud loop system transfer function as a function of jw. (See ref 14 for bandwidth definitions.)

Each of the basic frequency-domain specifications will be discussed briefly.

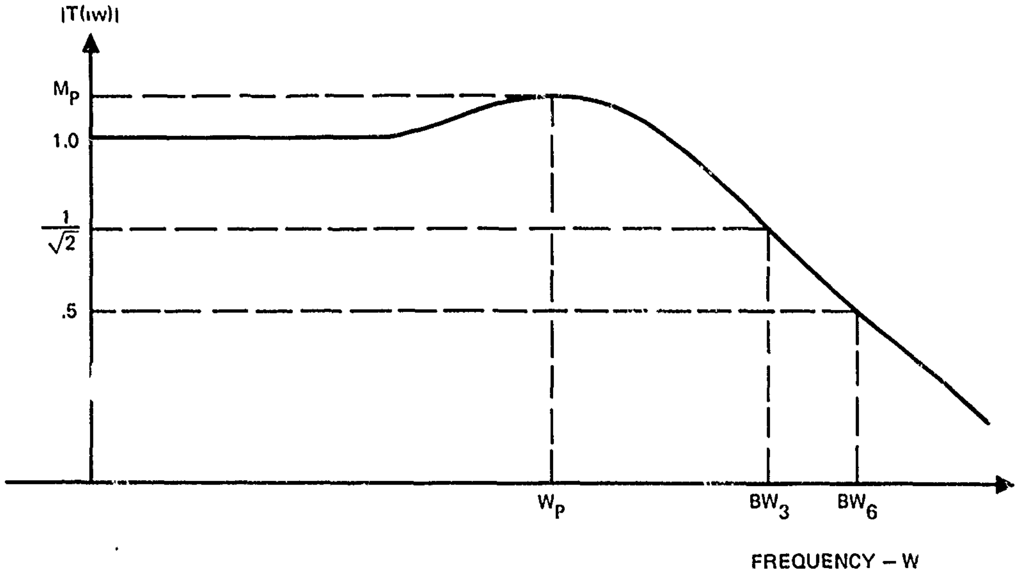


Figure 21. Frequency-domain performance specification definitions.

14. Watkins, BO, Introduction to Control Systems, the MacMillan Company, New York, 1969.

C. BANDWIDTH BW

BW is probably the most significant performance specification as it gives indication of the speed of response. Horowitz [ref 3], pages 192 and 194, presents an empirical formula with the rise time to the bandwidth. However, noise rejection and price considerations require low BW. The choice of BW is thus a compromise affair that will differ from case to case.

M Peak, M_p, and Peak Frequency W_p

These quantities are basically stability specifications. The magnitude of the peak relates to the settling time (refer to time-domain specifications), ie, the time required for the oscillations to die out. There is also a correlation between M_p and the sharpness with which the magnitude falls off with the percent overshoot. Jaworski [ref 10] presents empirical transient formulae relationships between frequency-domain and time-domain performance specifications.

Output Impedance Z

A maximum specification on Z will guarantee that the servo will perform properly over the expected load range. It is particularly important to realize that Z will vary with frequency, and it is therefore necessary to specify its peak value. The corresponding time-domain specification, compliance, is obviously not sufficient to predict intolerable output oscillations that could result from periodic load variations if applied at a frequency corresponding to peak impedance.

It should be stressed that the impedance specifications make sense only in those cases where, in reality, we can expect load fluctuations.

Time-Domain Specifications

Probably the most common of all performance specifications are those that relate the transient output of a system to a test input, usually in the form of a step function. Conceivably, one could specify time-domain performance specifications in terms of many various types of test inputs, and it is therefore appropriate to give some of the reasons why we chose this particular one:

1. A step is easy to apply and is sufficiently drastic.
2. No physical system is capable of following a step completely.
3. A large amount of information is available in the literature relating to this type of test input.
4. From a knowledge of the step-function response, it is possible to compute the response for any arbitrary input.

The last fact is demonstrated in figure 22. We wish to compute the response at time t for the general input function $i(\tau)$, assuming that we know, either from analysis or

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10. Jaworski, ZE, Empirical Transient Formulae, Electronic Engineering, September, 1954.

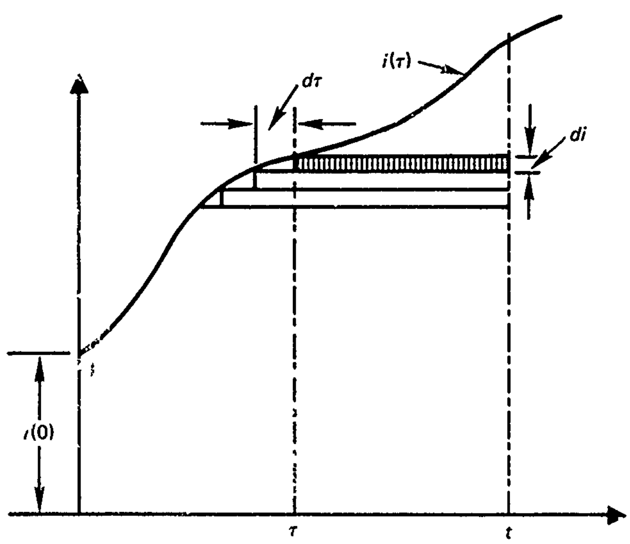

Figure 22. A general signal $i(\tau)$ can be considered as composed of elementary step functions.

from experiment, the response $g(\tau)$ for a unit step input applied at $t = 0$. The input function $i(\tau)$ can be considered composed of the infinitesimal step functions shown shaded in the figure.

By superposition, we obtain the output at time t from all these step functions of amplitude di plus the initial step of magnitude $i(0)$:

$$o(t) = i(0)g(t) + \int_0^t g(t - \tau)\, di = i(0)g(t) + \int_0^t g(t - \tau)\frac{di}{d\tau}\, d\tau$$

$$= i(0)g(t) + \int_0^t g(t - \tau)i'(\tau)\, d\tau$$

As in the case of frequency-domain performance specifications, we find that the literature abounds with suggested figures of merit. The five time-domain performance specifications which will be used are:

1. Delay time T_D
2. Rise time T_R
3. Percentage overshoot PO
4. Settling time T_S
5. Final (static) value of error FVE.

These are illustrated in figure 23. Explanation of these time-domain performance specifications is expanded in the following paragraphs.

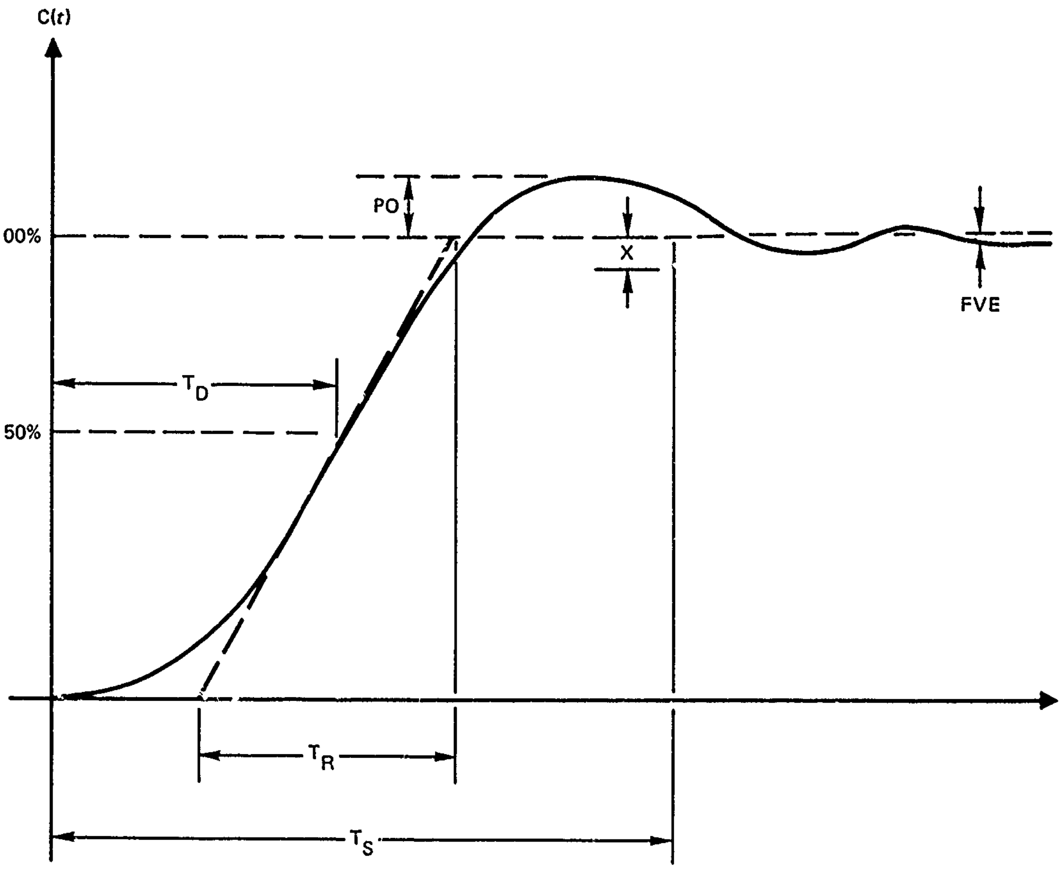

Figure 23. Time-domain performance specification definitions.

Delay Time T_D

This quantity is a meas· re of the "delay" of the servo and is defined as the time interval between the applicatior. of the input step and the moment when a substantial output is observed, usually defined ‹ s 50 percent of the step amplitude. The delay time is closely associated with the second item in the set of PS, the rise time.

Rise Time T_R

This quantity expresses the sharpness of the leading edge of the output. Several definitions exist the one suggested here is based upon the rate of the pulse increase at the moment the output pulse "arrives," ie, at time T_D. Both delay and rise time are closely related to the bandwidth specification in the frequency domain.

Overshoot PO and Settling Time T_S

These two quantities specify the degree of stability of the servo. They therefore are closely associated with M peak and peak frequency in the frequency domain. T_S is defined as the time it takes for the output to settle down within a specified x percent of the final value.

Time-domain specifications are those which are generally used to specify system performance. In the design procedure, however, it is often easier to work in the frequency domain. The synthesis processes can then be one of relating frequency-domain specifications to time-domain specifications. Analytically this is quite easily done for a second order system. Melsa and Schultz [ref 11] present a thorough treatment of relating time-domain to frequency-domain specifications for second- and third-order systems. Figures 24(A) and (B) present frequency- and time-domain performance specifications with tolerances specified by the shaded areas. The synthesis procedure is to examine, in the frequency domain, the magnitude of the closed loop system response. By knowing the mapping from the frequency to time-domain, the time-domain specifications can be evaluated. If requirements are not met (in the time domain), system parameters can be changed and the frequency-domain specifications reexamined. As can be seen this is an iterative process. Since the mapping between frequency and time-domain specifications (for higher order systems) is based on empirical relations, the procedure is somewhat trial and error. Trial and error is probably the most widely used synthesis procedure. Elgerd [ref 9] classifies synthesis methods into three categories (trial-and-error, analytical, and optimal). For the classical control system problem the trial-and-error is the most useful and widely used.

3.3.1 Slave Loop Performance Specification

The designer has, for classical control system design, another means of specifying system performance. This is with the error constants. Basically those most commonly used are the acceleration-error constant, position-error constant and velocity-error constant. Refering to the time-domain specifications for a step input, the error defined in figure 24B as the final value of error relates directly to the error constant. The slave loop is a Type 1 system, therefore it has a zero final value error for a position input. As will be seen in the following section, the acceleration error constant will be of importance to the design of the track/stabilization loop. The desired performance specifications for the inner and outer gimbal for the slave loop design are presented in table 2.

3.3.2 Stabilization/Track Loop Performance Specifications

The stabilization/track loop is quite different from slave loop. Its function is to provide an estimate of the line-of-sight rate to the guidance computer by means of a rate tracking servo loop. The sensor is stabilized such that it is an inertial reference. This is required for low data rate systems. The sensor maintains its look angle in inertial space even during loss of tracking data. The stabilization loop is designed to have a very high acceleration constant and an infinite K_V.

11. Melsa, JL, and Schultz, DG, Linear Control Systems, McGraw-Hill Book Company, 1969.

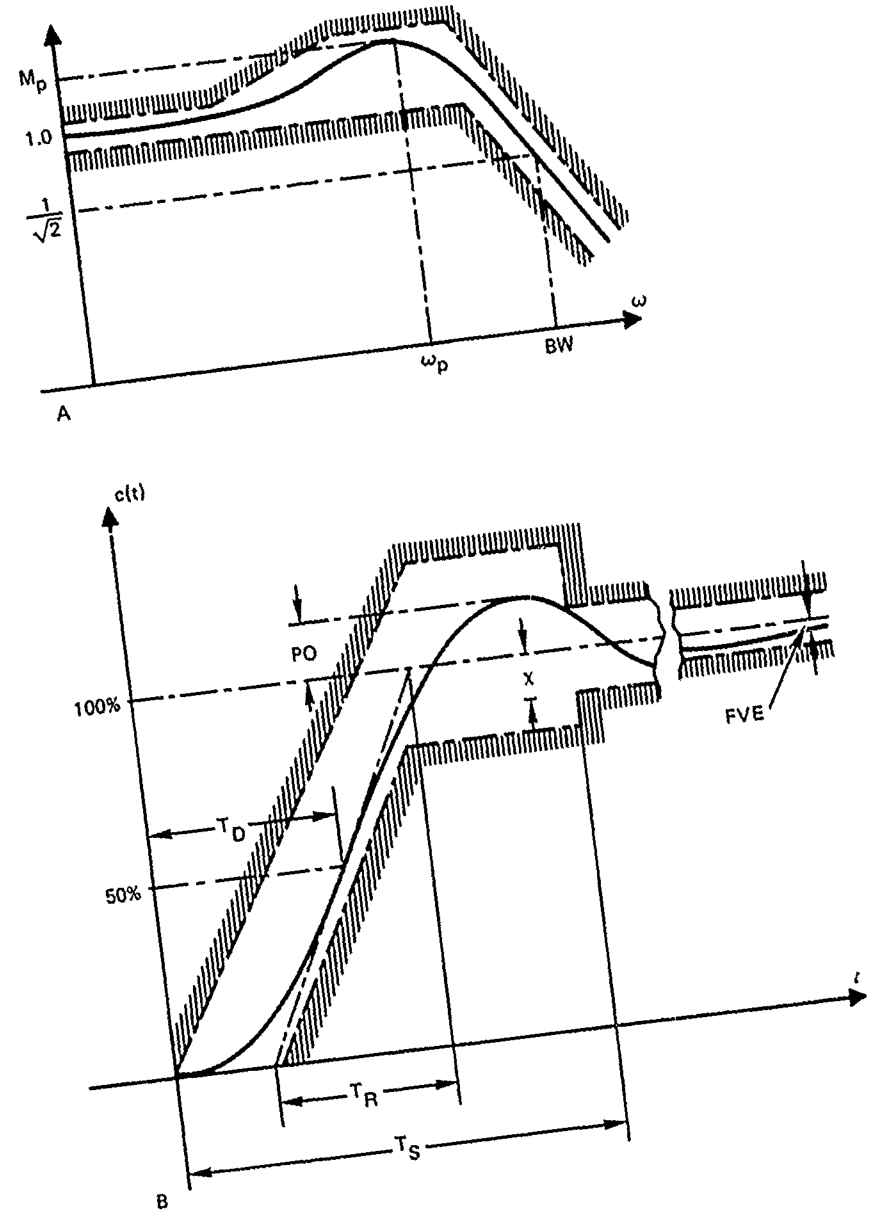

Figure 24. Frequency- and time-domain performance specifications.

Design/Performance Parameters	Inner Gimbal	Outer Gimbal
Rise Time	.025 sec	.025 sec
Delay Time	.01 sec	.01 sec
Percent Overshoot	10%	10%
Settling Time	.1 sec	.1 sec
Velocity Error Constant	40,000.00	40,000.00
BW	200 rad 30 Hz	200 rad 30 Hz
M_p	3 dB	3 dB

Table 2. Slave loop design specifications.

Infinite K_V implies zero steady state rate tracking error. The more paramount design requirements placed on the stabilization/track loop is the isolation design requirements. These design requirements are isolation of the estimated rate tracking signal and pointing error from extraneous rate signals and disturbance torques. The higher the acceleration error constant, the better the isolation achieved.

The isolation properties from extraneous disturbance signals are functions of frequency. Therefore, the design requirements must specify the minimum isolation over a frequency region. This frequency region is usually tied to the airframe characteristics for the particular airframe in which the stabilized platform will be used. The short period poles of the airframe transfer function characterize the higher frequency natural resonances in the airframe/autopilot system. The design goal is to have the isolation of the disturbance signals reach their minimum values beyond the natural frequency responses of the airframe/autopilot.

The isolation properties for extraneous signals (for a type II system) all have the same general characteristics; see figure 25. For low frequencies isolation is large. It reaches a minimum and then increases with increasing frequencies.

The desired design specifications for the track/stabilization loop (inner and outer gimbals) are presented in tables 3 and 4.

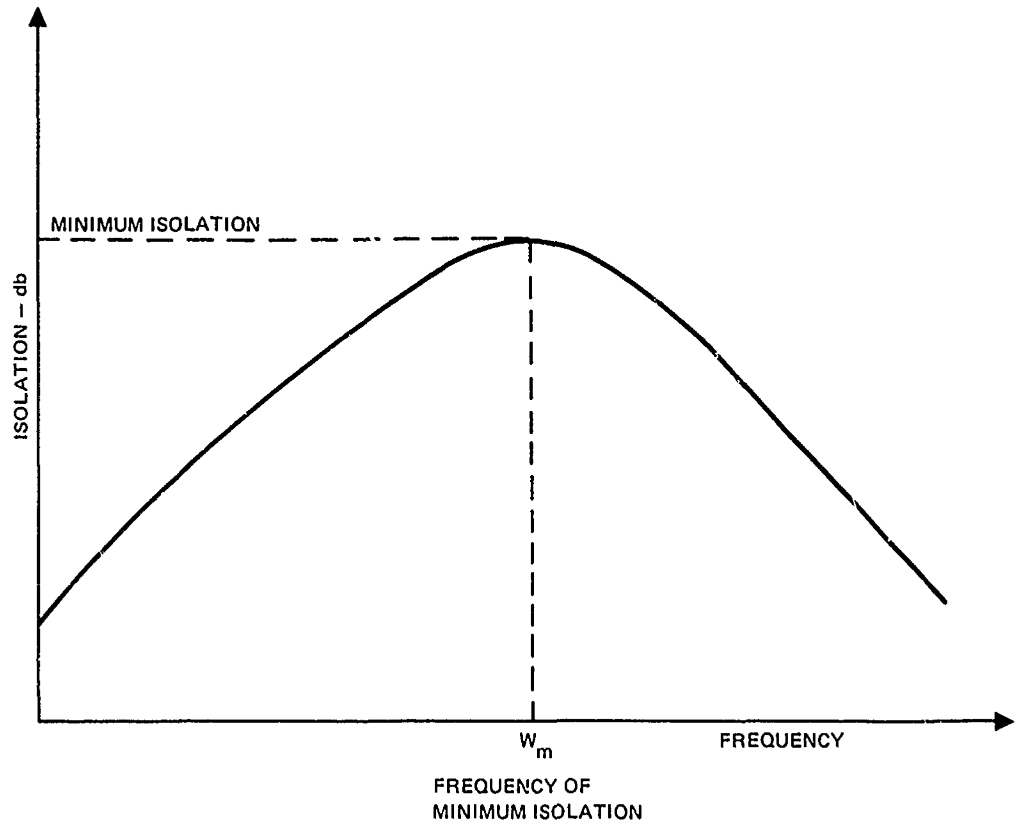

Figure 25. Typical isolation curve.

Design/Performance Parameters	Inner Gimbal	Outer Gimbal
Rise Time	0.005 sec	0.005 sec
Delay Time	0.002 sec	0.002 sec
Percent Overshoot	20%	20%
Settling Time	0.1 sec	0.1 sec
Acceleration Error Constant	200,000.00	250,000.00
BW	500 rad	500 rad
M_p	3 dB	3 dB

Table 3. Stabilization loop design specifications.

Design/Performance Parameters	Inner Gimbal (Isolation – dB)	Outer Gimbal (Isolation – dB)
Maximum Tracking Rate	100 deg/sec	100 deg/sec
Minimum Isolation:		
$\left.\frac{\hat{\dot{\sigma}}}{\dot{\theta}}\right\|_{S = 1;\ 10\ \text{rad}}$	80; 60	80; 60
$\left.\frac{\hat{\dot{\sigma}}}{Td}\right\|_{S = 1;\ 10\ \text{rad}}$	100; 60	100; 60
$\left.\frac{\epsilon}{\dot{\theta}}\right\|_{S = 1;\ 10\ \text{rad}}$	100; 60	100; 60
$\left.\frac{\epsilon}{Ta}\right\|_{S = 1;\ 10\ \text{rad}}$	100; 80	100; 80

Table 4. Track loop design specifications.

4. STABILIZED PLATFORM DESIGN PERFORMANCE

The stabilized sensor platform was designed to meet the performance requirements as specified in the previous sections. This section briefly presents the design performed for each of the modes of the stabilized sensor platform.

4.1 SLAVE LOOP DESIGN PERFORMANCE

Figures 26 through 37 present the design and performance characteristics of the slave loop for both the inner and outer gimbals.

For the outer gimbal the open loop uncompensated frequency response is presented in figure 27. The loop frequency response after being compensated is shown in figure 29. This figure presents the gain and phase margins for the slave loop outer gimbal. The phase margin is 40 degrees and the gain margin is 20 dB. The closed loop frequency response (response from which the bandwidth can be evaluated) is presented in figure 30. The time response for the slave loop outer gimbal is shown in figure 31. The inner gimbal design performance data is presented in figures 32 through 37.

The summary section of this report presents the design configurations and the design performance for each of the servo loops. Much of the performance criterion presented in table form in the Summary section was summarized from the curves and figures presented in this section.

4.2 STABILIZATION LOOP DESIGN PERFORMANCE

Figures 38 through 47 relate to the stabilization loop design (inner and outer gimbals) and the design performance criterion. Specifically, figures 38 through 42 deal with the inner gimbal while figures 43 through 47 deal with the outer gimbal. Figure 38 is the frequency plot of the uncompensated loop. The magnitude of the frequency response reaches zero dB after the phase reaches a minus 180 degrees. In fact the phase has reached approximately a minus 240 degrees, thus, some form of compensation is required. A comparison of figures 33 and 38 (open loop frequency response curves for the slave loop and stabilization) shows that the compensation network of the stabilization loop must increase the phase considerably over that of the slave loop compensation network. In addition to a lead network to increase the phase at the 0 dB crossover a low frequency lag network is added to allow the gain to be increased and yield a higher acceleration constant. The magnitude and phase plots of the stabilization network frequency response curve is shown in figure 39. The phase reaches a peak at approximately 500 radians, therefore, the closed loop bandwidth can be approximately set at 500 radians. By examining figures 40 and 41, the open loop and closed loop frequency response curves, it is seen that the system is stable (conditionally stable) and that the bandwidth is approximately 750 radians. The phase margin is 59 degrees. The gain margin, for increasing gain, is 12 dB and is 20 dB for decreasing gain. The time response for the stabilization loop is shown in figure 42. All of the nonlinearities of the system are reflected in the time response curve these nonlinearities are not included in the frequency response curves because frequency response techniques deal only with linear systems.

4.3 TRACK LOOP DESIGN PERFORMANCE

Figures 48 through 59 present the track loop performance data. Briefly these figures present data of disturbance isolation, closed loop frequency and time response characteristics of the track loop. Figures 48 through 53 present the outer gimbal data and figures 54 through 59 present the inner gimbal data. The isolation curves are used to establish the level of body or base motion that can be tolerated for acceptable tracking or steering information and the level of mass imbalance that is tolerable. The level of tolerable mass imbalance can be established from the extraneous torque disturbance isolation curves, figures 49 and 51. The maximum tracking rates are derived from the frequency response curve of figure 52. It is seen that a flat response is maintained out to 2 radians; that is, the estimated line-of-sight rate follows the true line-of-sight rate out to 2 rad/sec with no appreciable degradation. Again both inner and outer gimbal data is presented. Figures 48 through 53 are for the outer gimbal and 54 through 59 for the inner gimbal. Comparative statements of the inner gimbal data can be made in the same light as was done for the outer gimbal data.

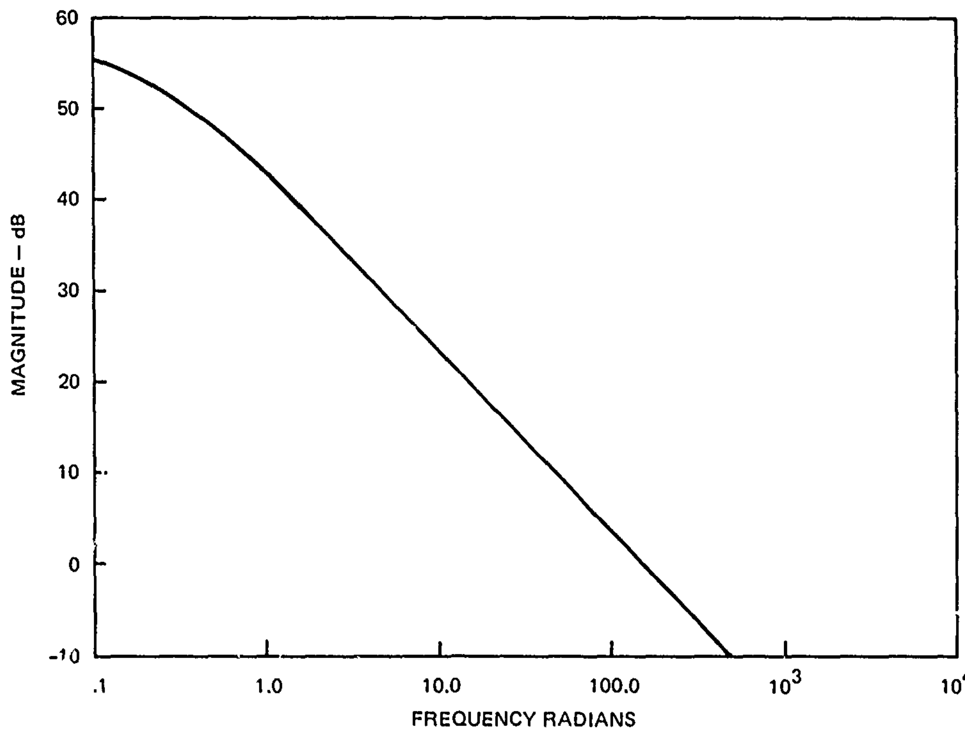

Figure 26. Servo amp/motor/load frequency response (inner gimbal).

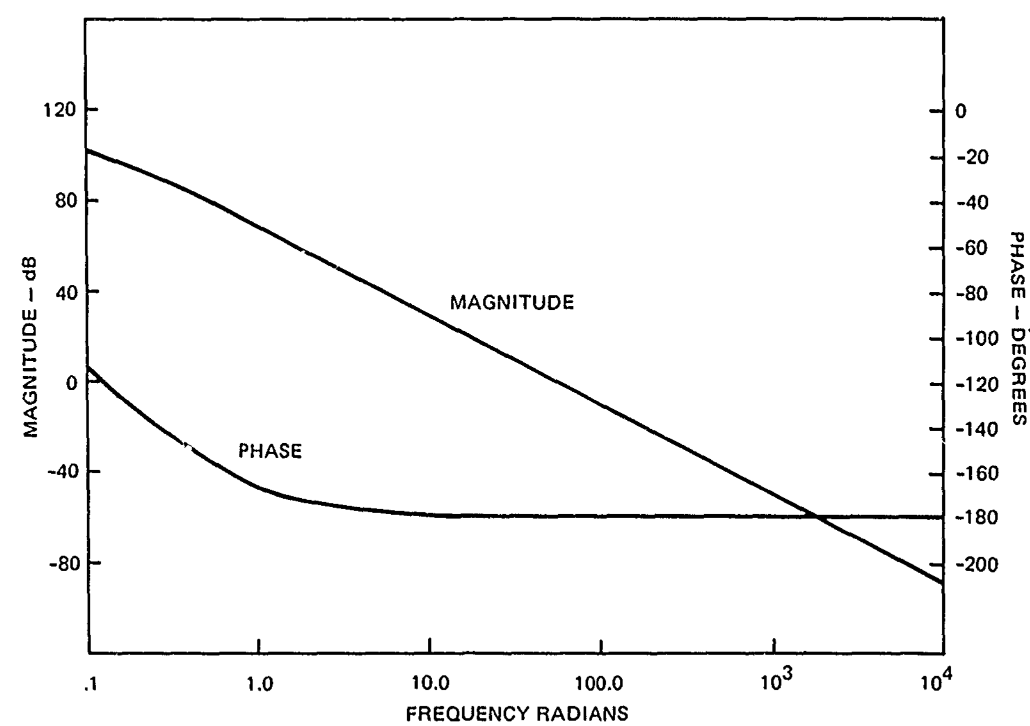

Figure 27. Slave loop (open loop) uncompensated frequency response (inner gimbal).

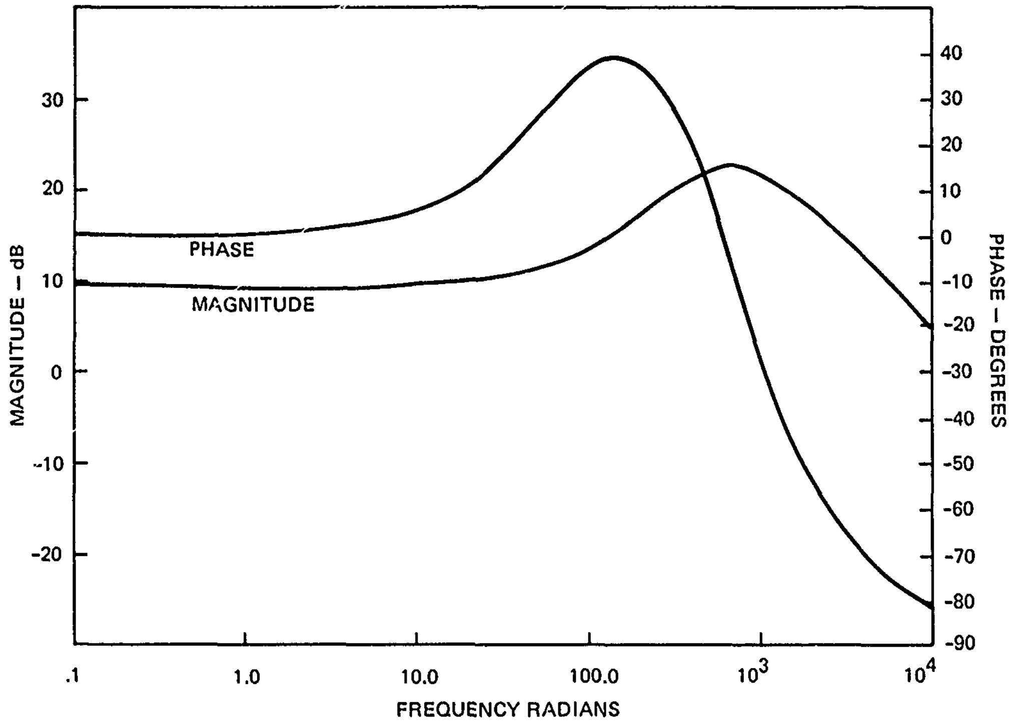

Figure 28. Slave loop compensation network frequency response (inner gimbal).

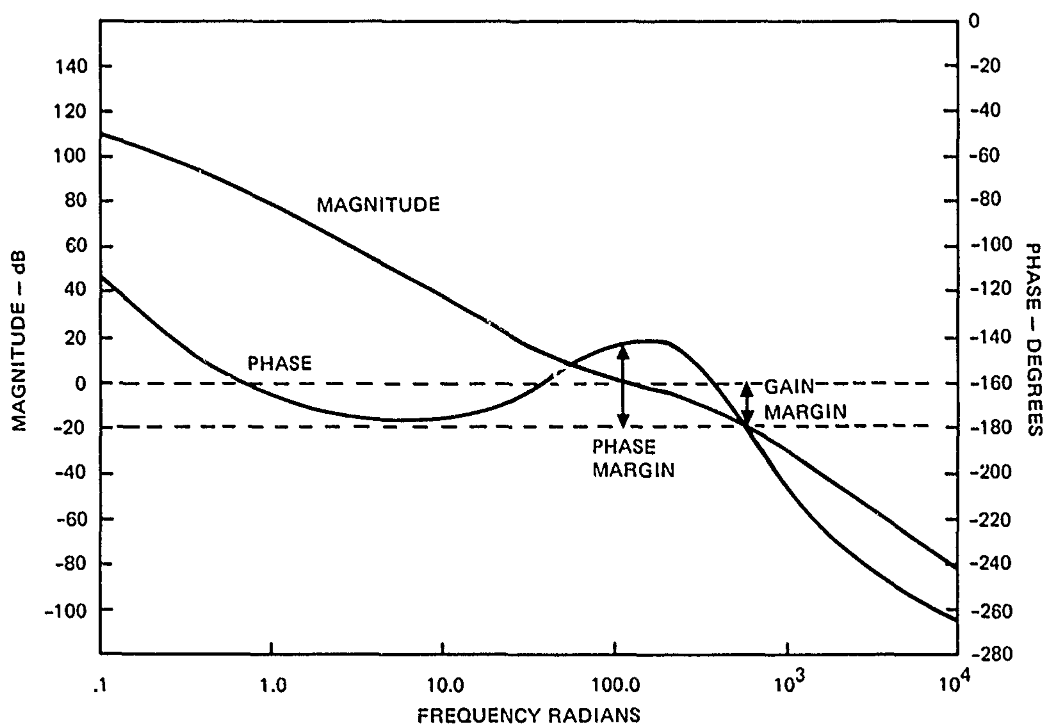

Figure 29. Compensated slave loop (open loop) frequency response (inner gimbal).

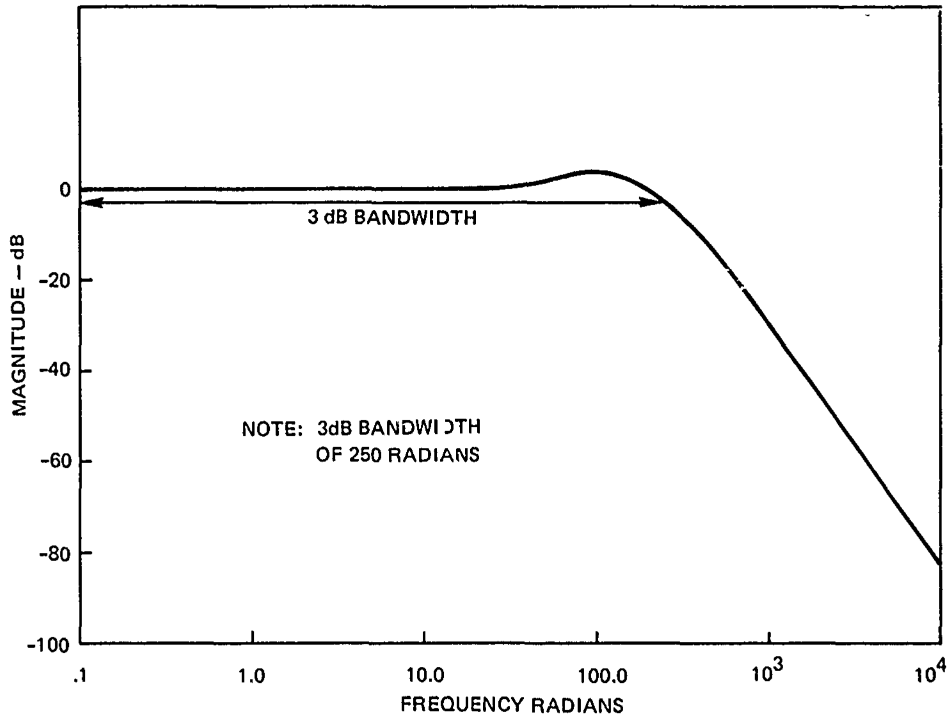

Figure 30. Slave loop (closed loop) frequency response (inner gimbal).

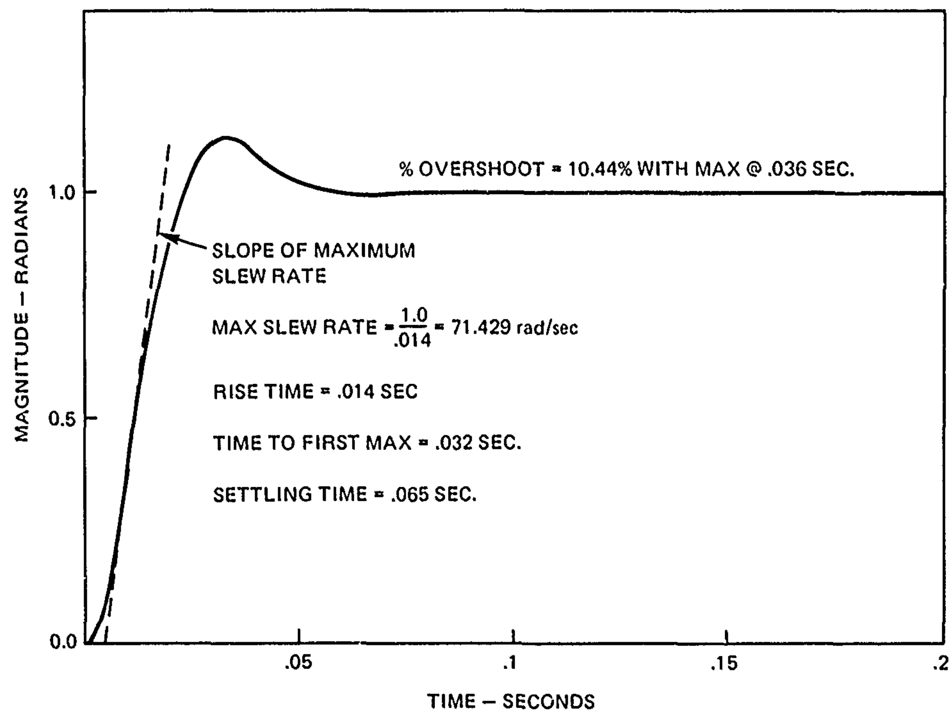

Figure 31. Slave loop inner gimbal time response.

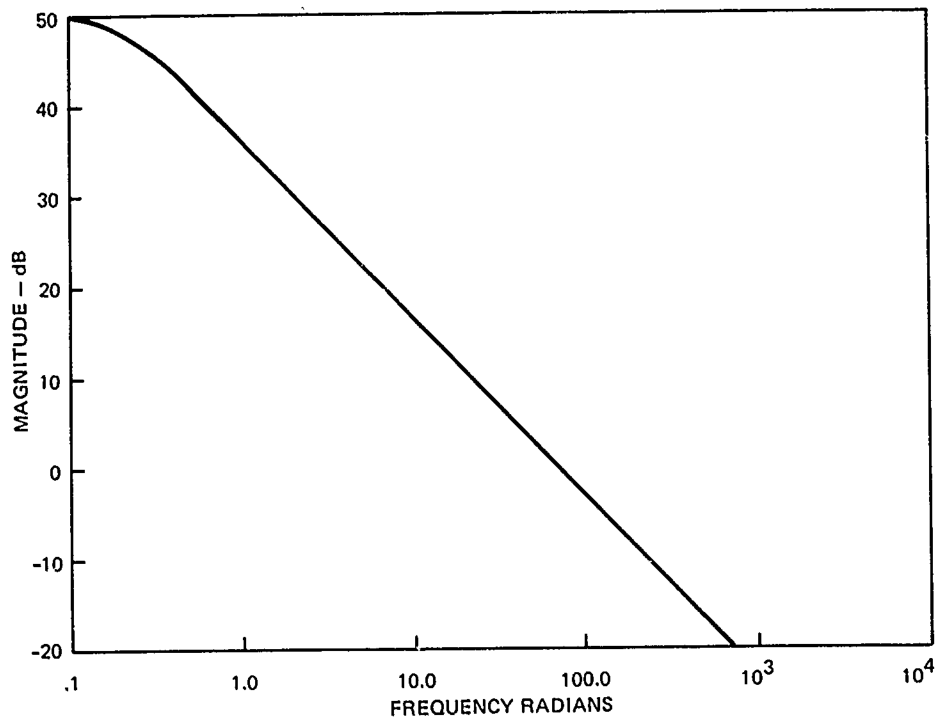

Figure 32. Servo amp/motor/load frequency response (outer gimbal).

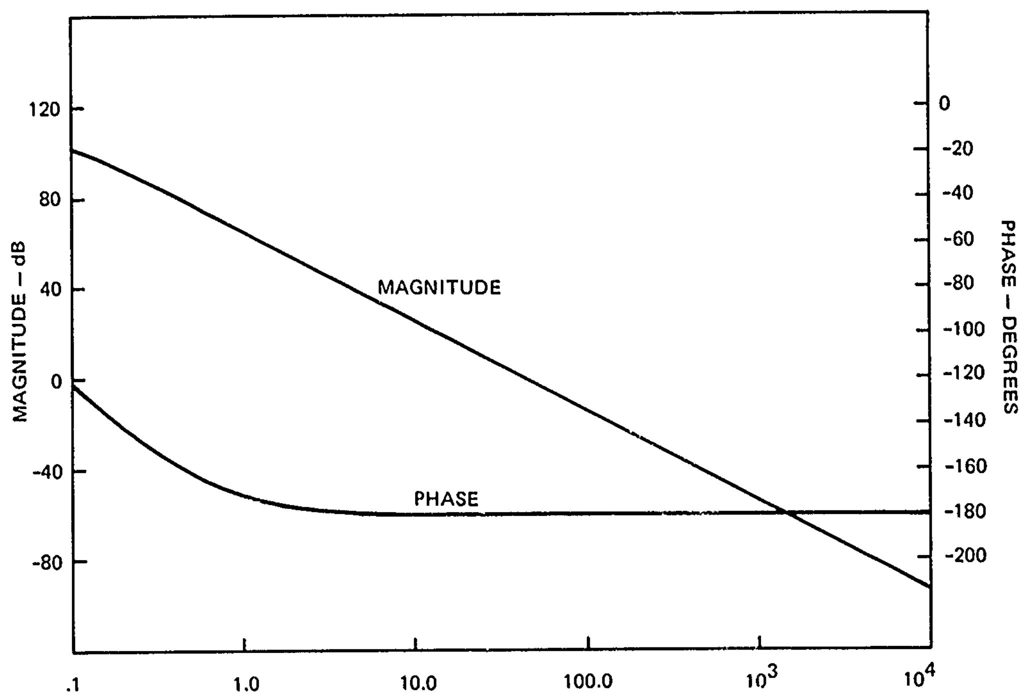

Figure 33. Slave loop (open loop) uncompensated frequency response (outer gimbal).

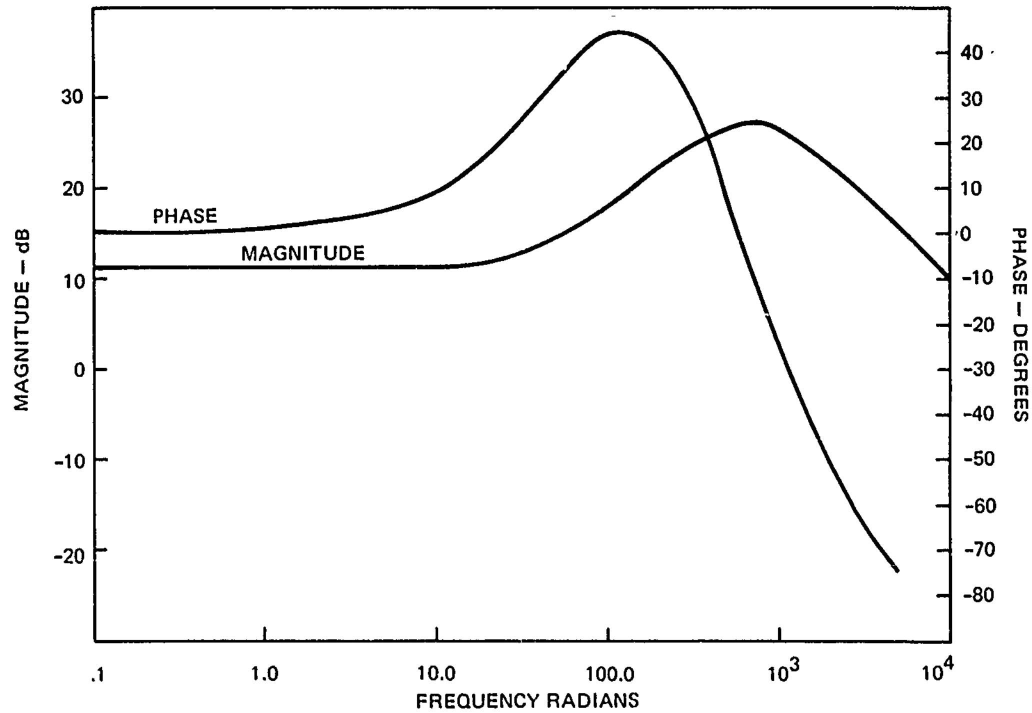

Figure 34. Slave loop compensation network frequency response (outer gimbal).

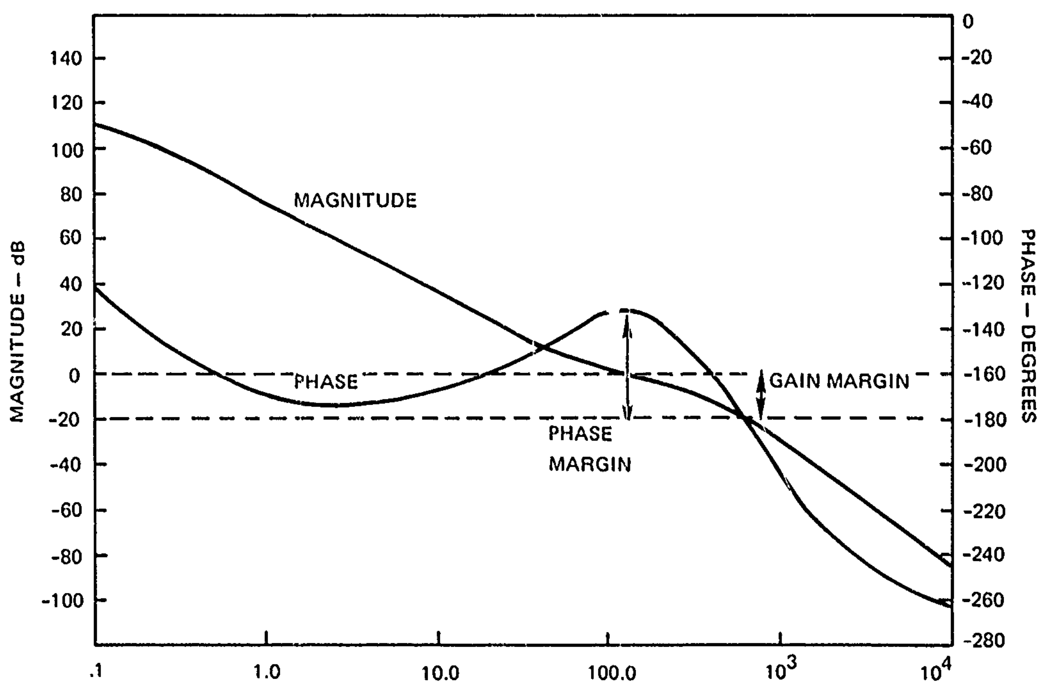

Figure 35. Compensated slave loop (open loop) frequency response (outer gimbal).

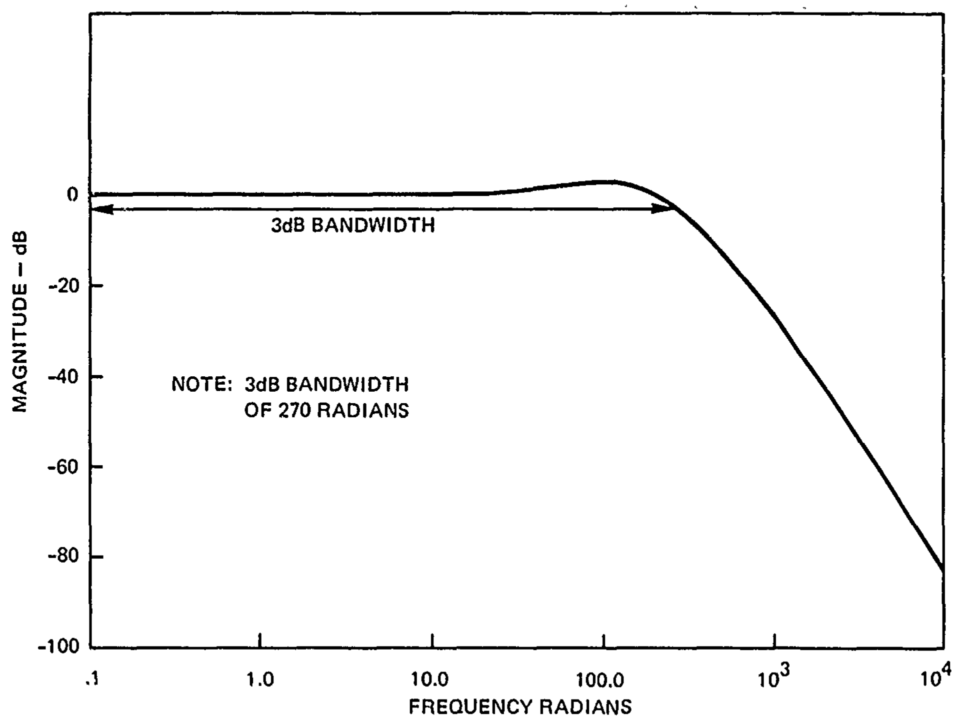

Figure 36. Slave loop (closed loop) frequency response (outer gimbal).

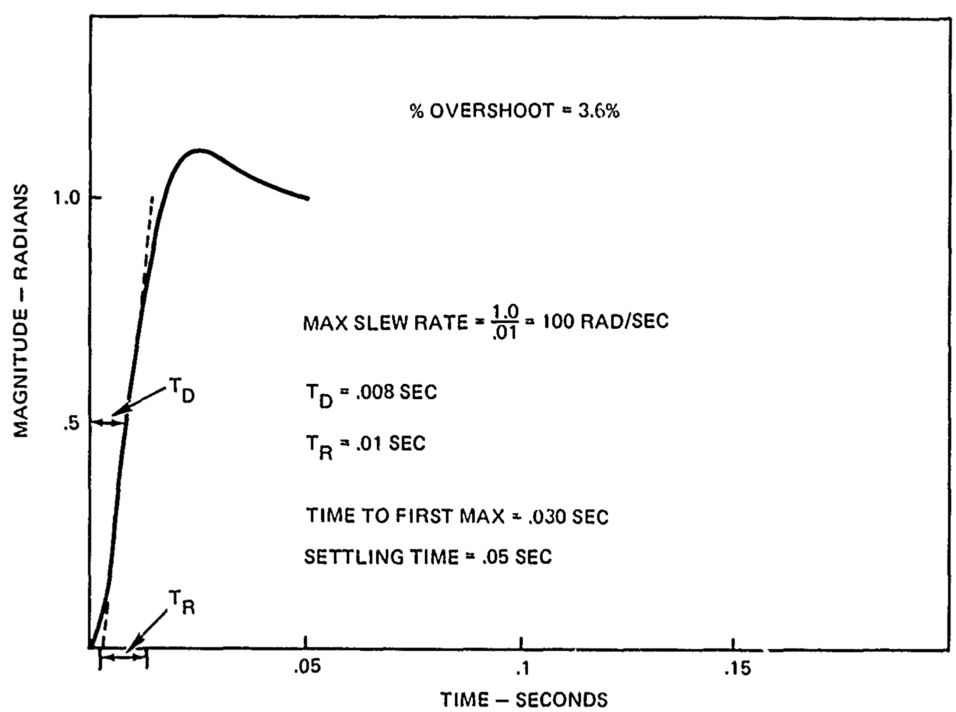

Figure 37. Slave loop outer gimbal time response.

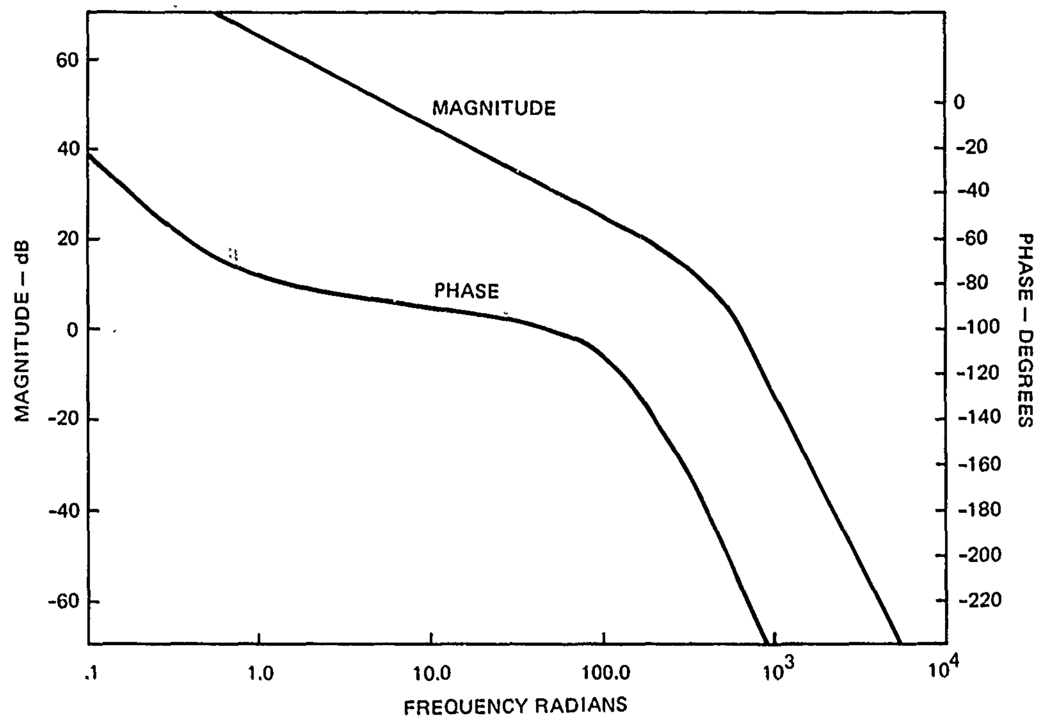

Figure 38. Stabilization loop frequency response (inner gimbal) uncompensated.

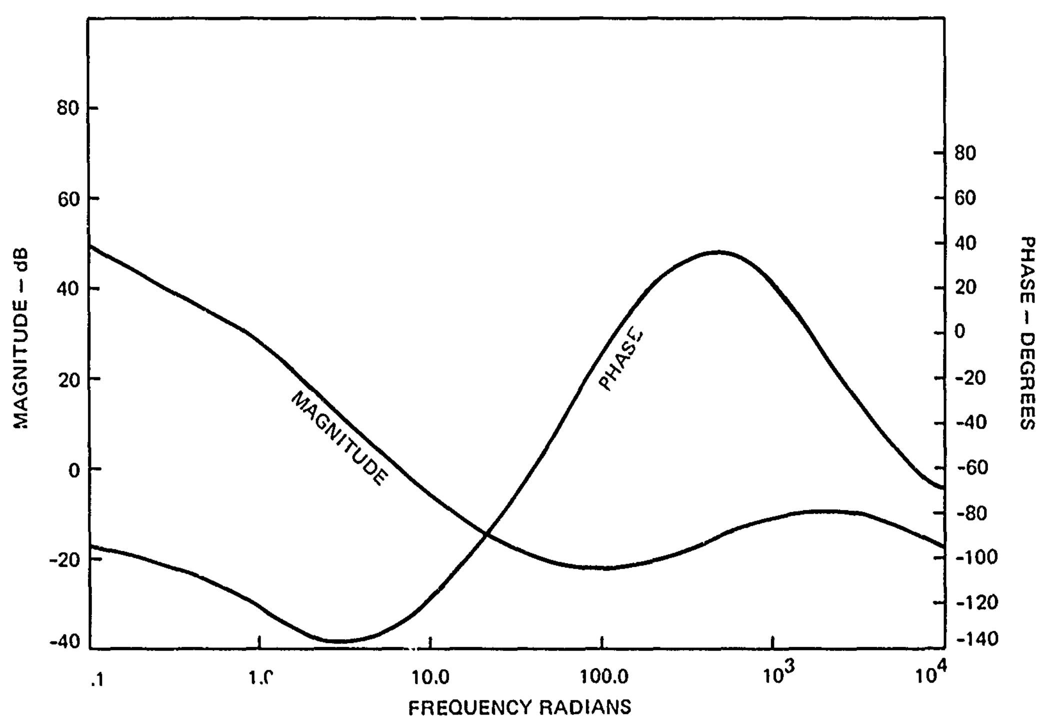

Figure 39. Stabilization loop compensation – inner gimbal.

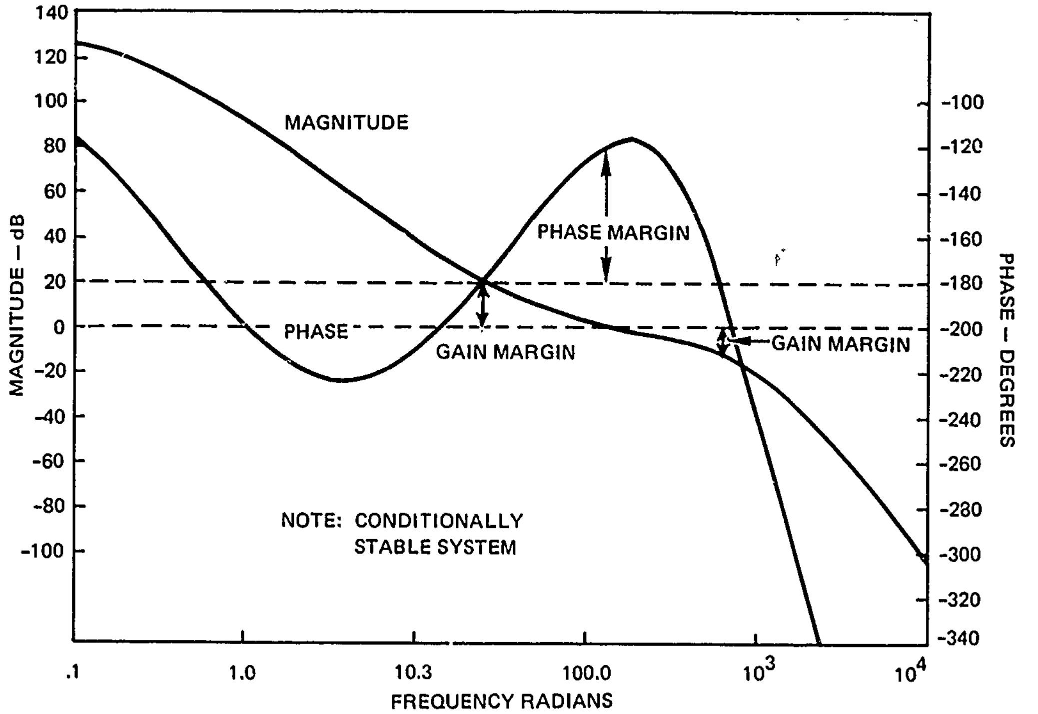

Figure 40. Stabilization loop frequency response compensated (inner gimbal).

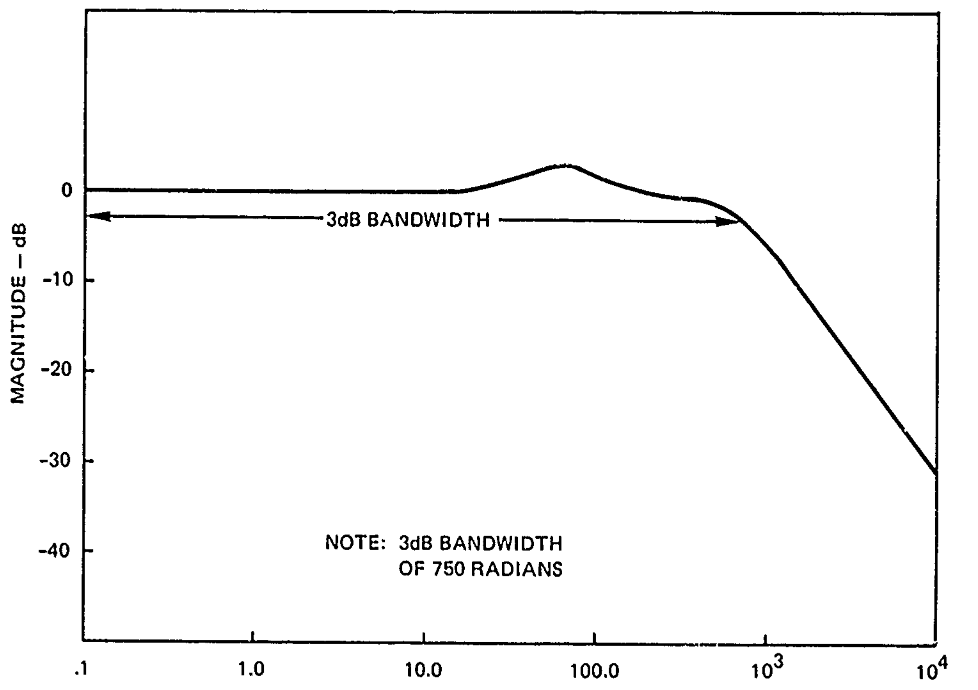

Figure 41. Stabilization closed loop frequency response (inner gimbal).

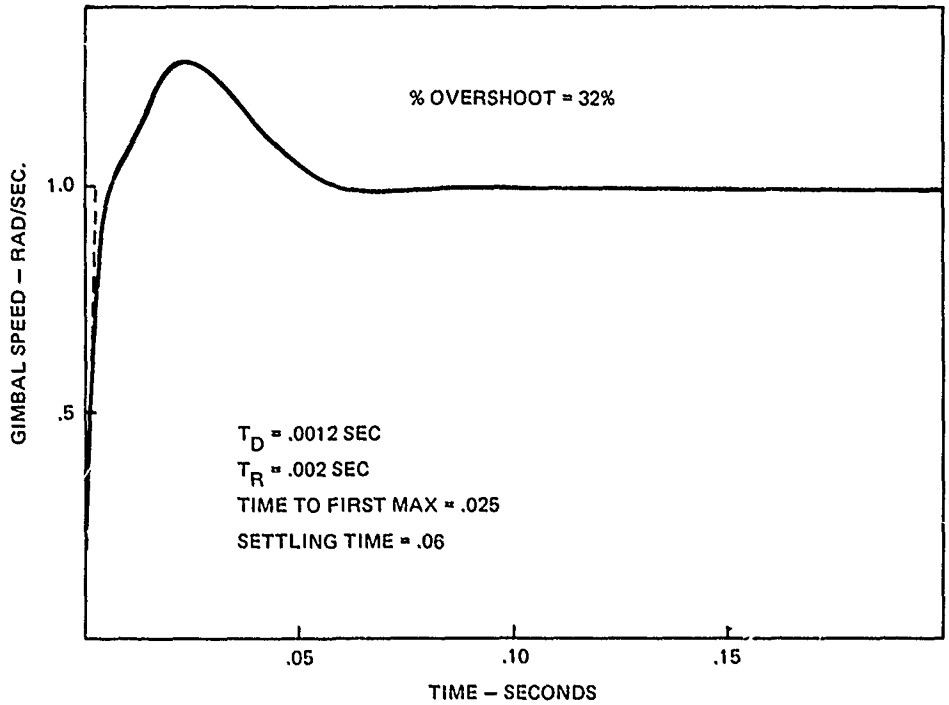

Figure 42. Stabilization loop time response (inner gimbal).

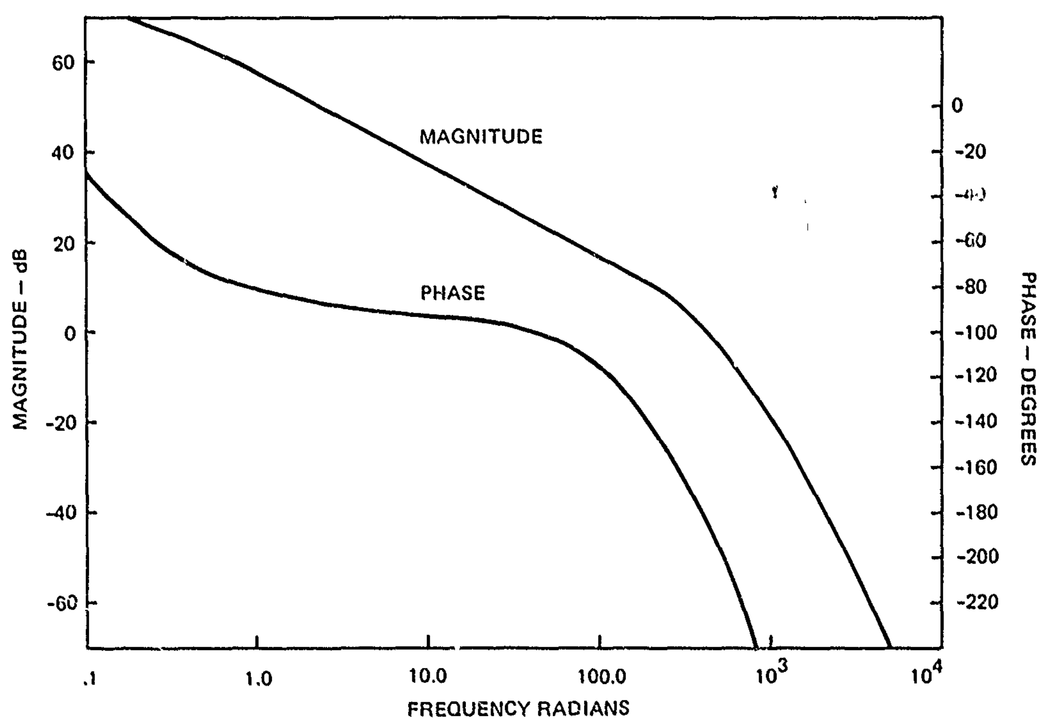

Figure 43. Stabilization loop frequency response (outer gimbal) uncompensated.

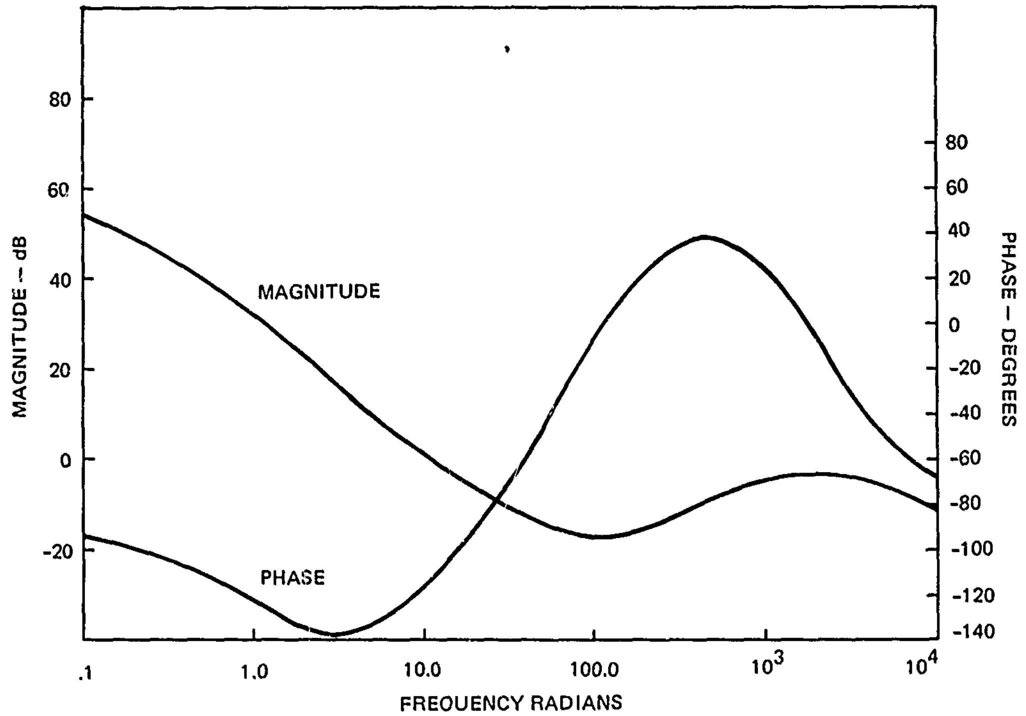

Figure 44. Stabilization loop compensation – outer gimbal.

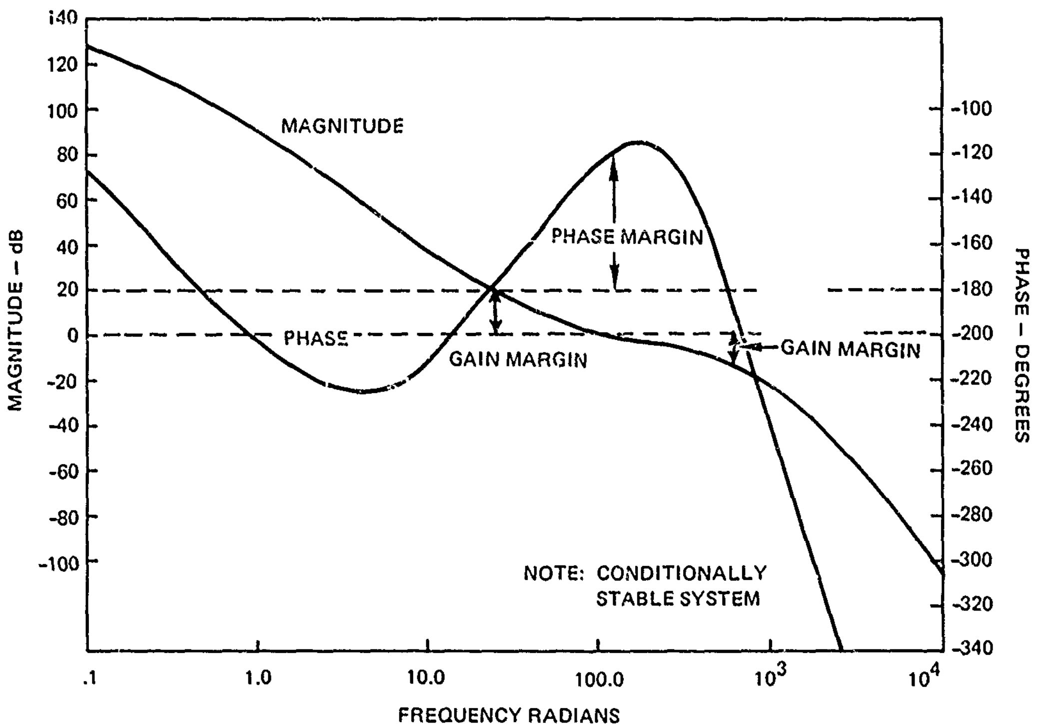

Figure 45. Stabilization loop frequency response compensated (outer gimbal).

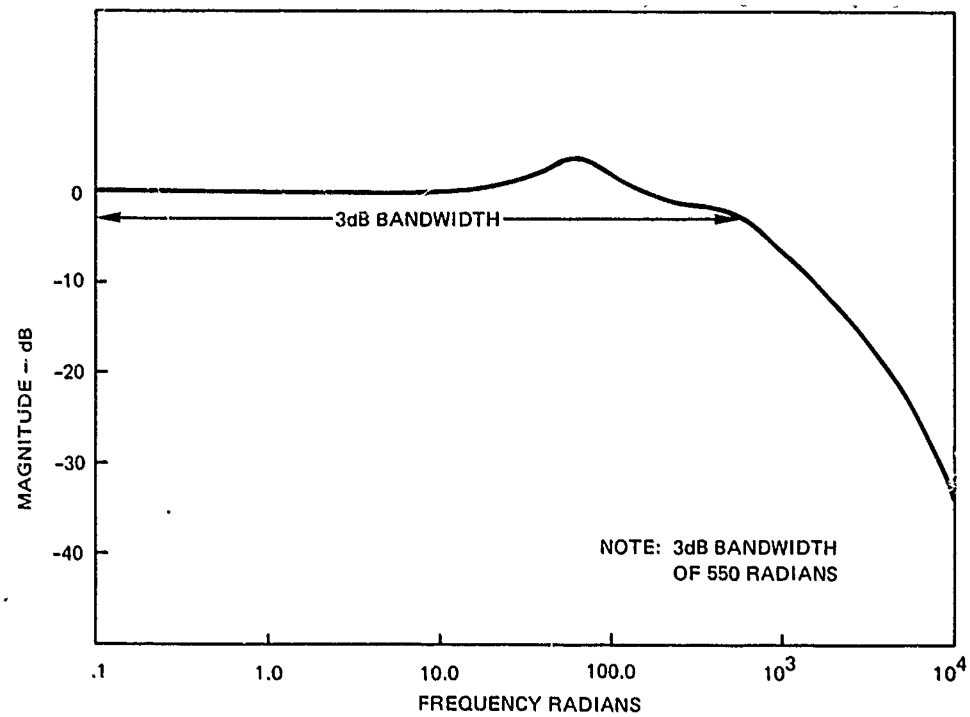

Figure 46. Stabilization closed loop frequency response (outer gimbal).

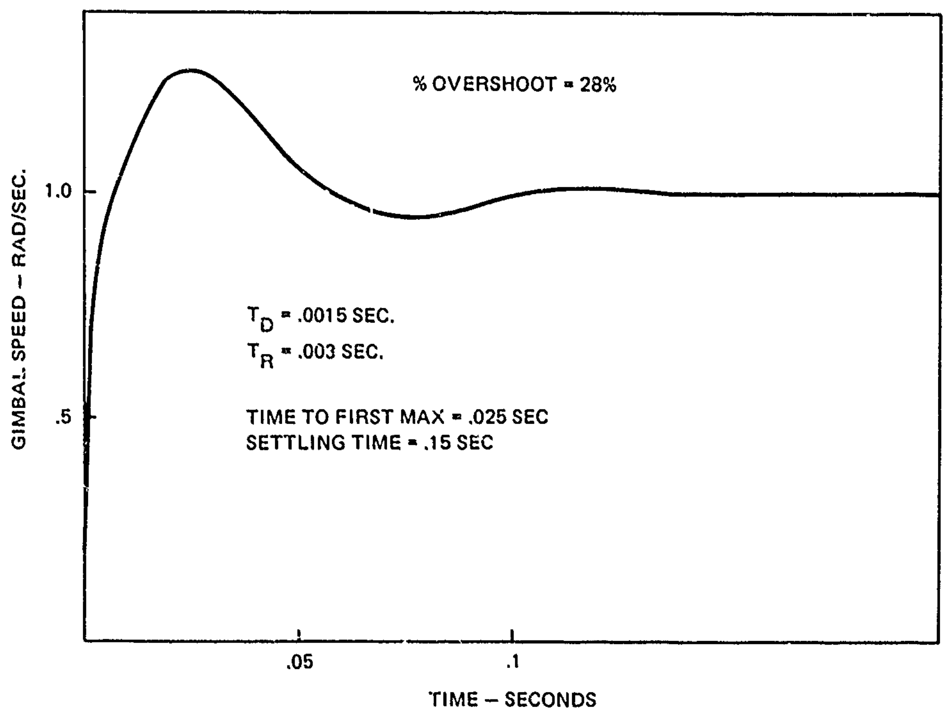

Figure 47. Stabilization loop time response (outer gimbal).

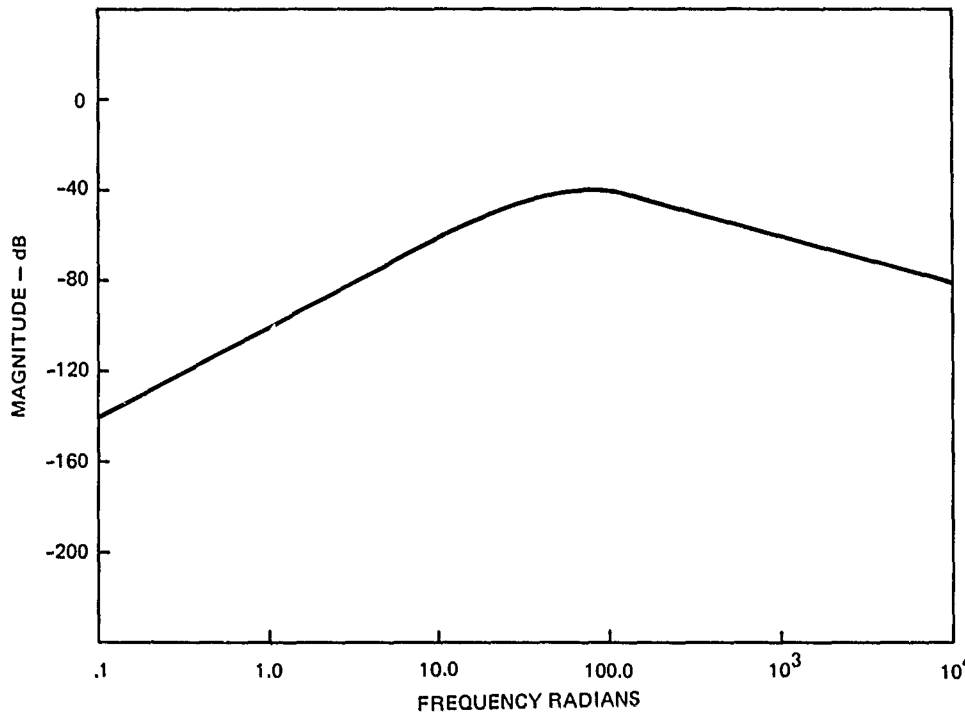

Figure 48. Frequency response of pointing error to body motion disturbance $\epsilon/\dot{\theta}$ (outer gimbal).

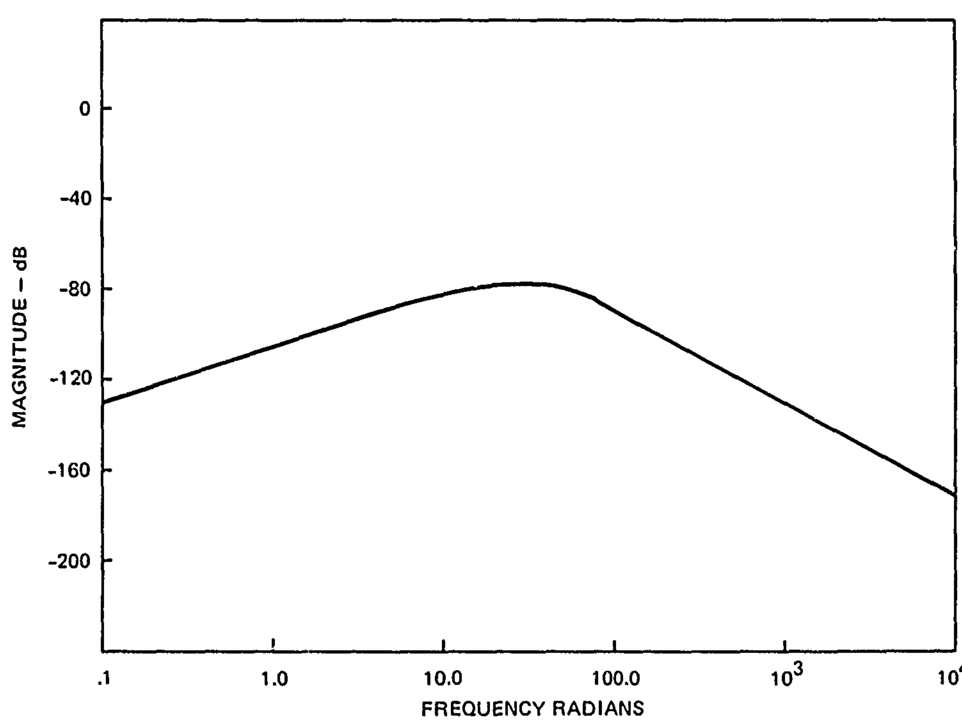

Figure 49. Frequency response of pointing error to torque disturbance ϵ/Td (outer gimbal).

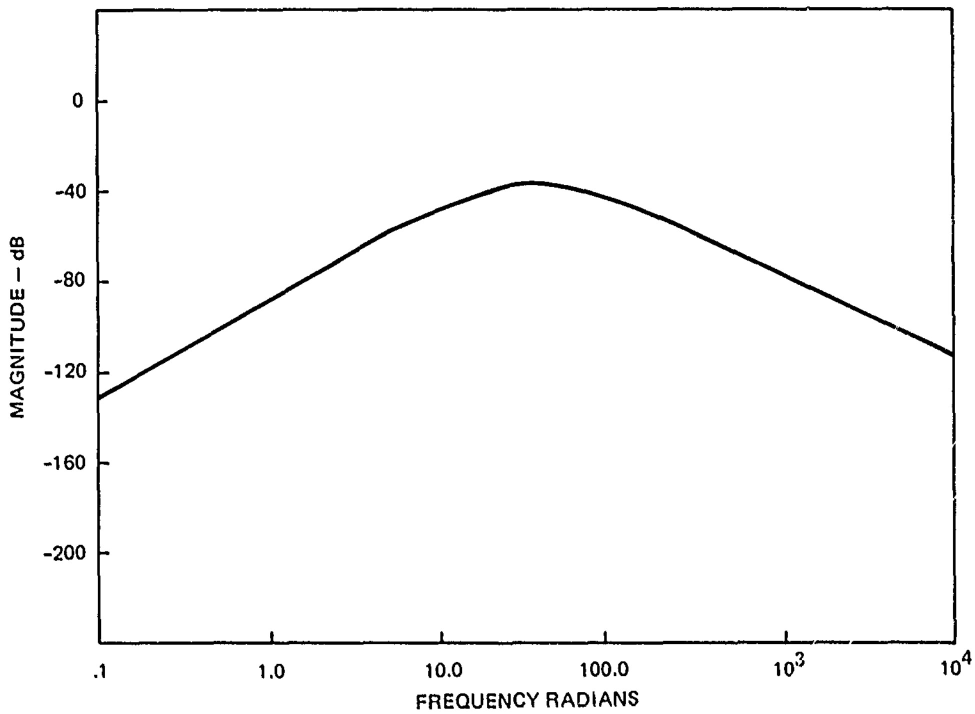

Figure 50. Frequency response of estimated line-of-sight to body motion disturbance $\hat{\sigma}/\dot{\theta}$ (outer gimbal).

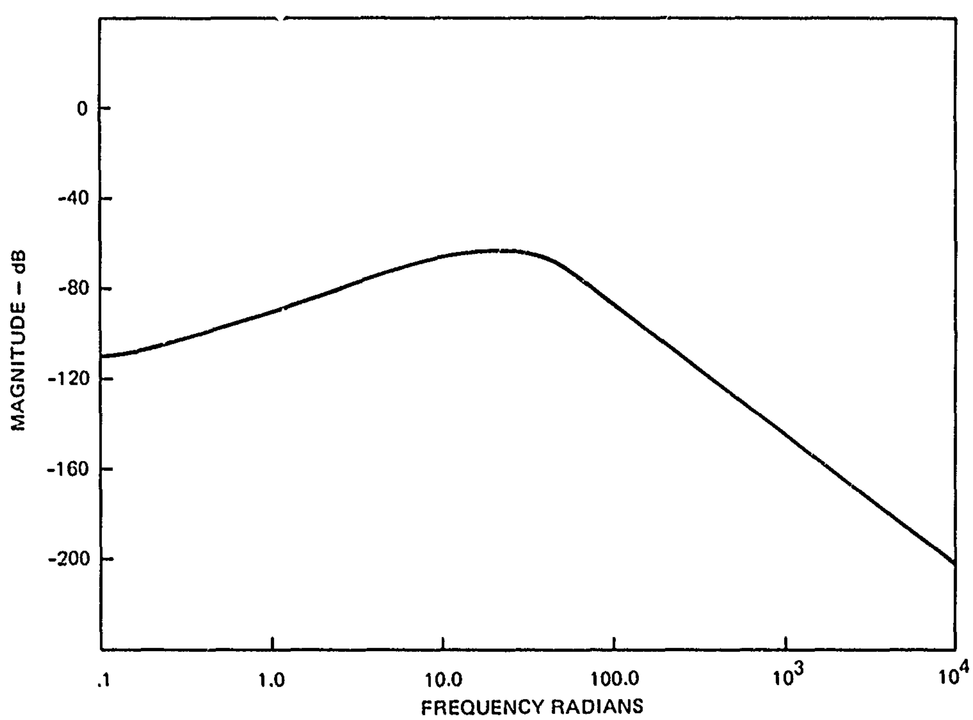

Figure 51. Frequency response of estimated line-of-sight to torque disturbance $\hat{\sigma}$/Td (outer gimbal).

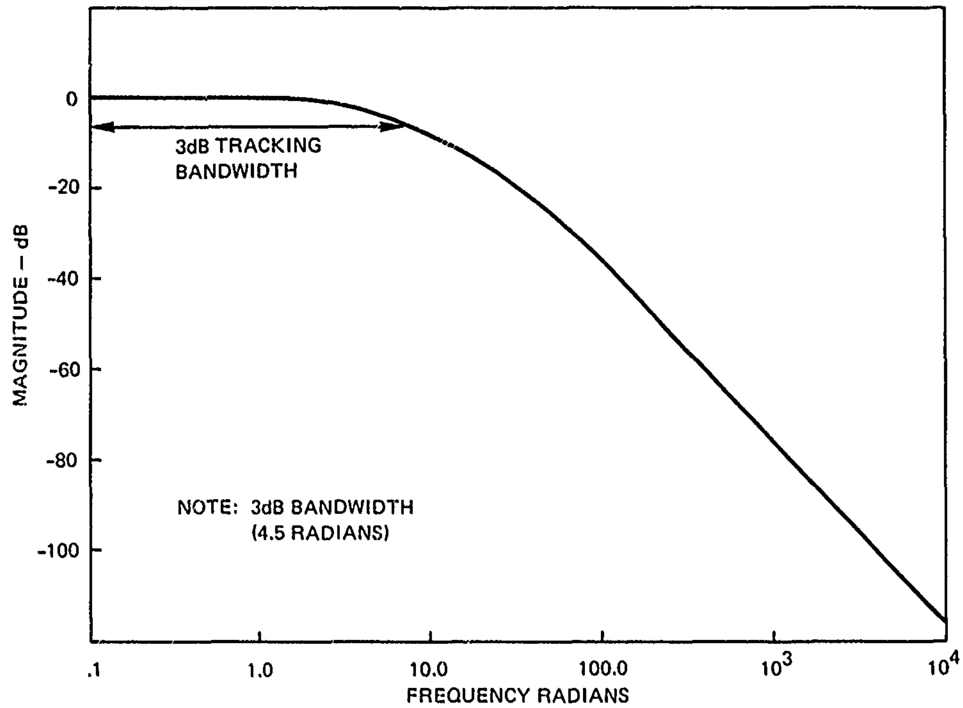

Figure 52. Frequency response of track loop $\hat{\dot{\sigma}}/\dot{\sigma}$ transfer function (outer gimbal).

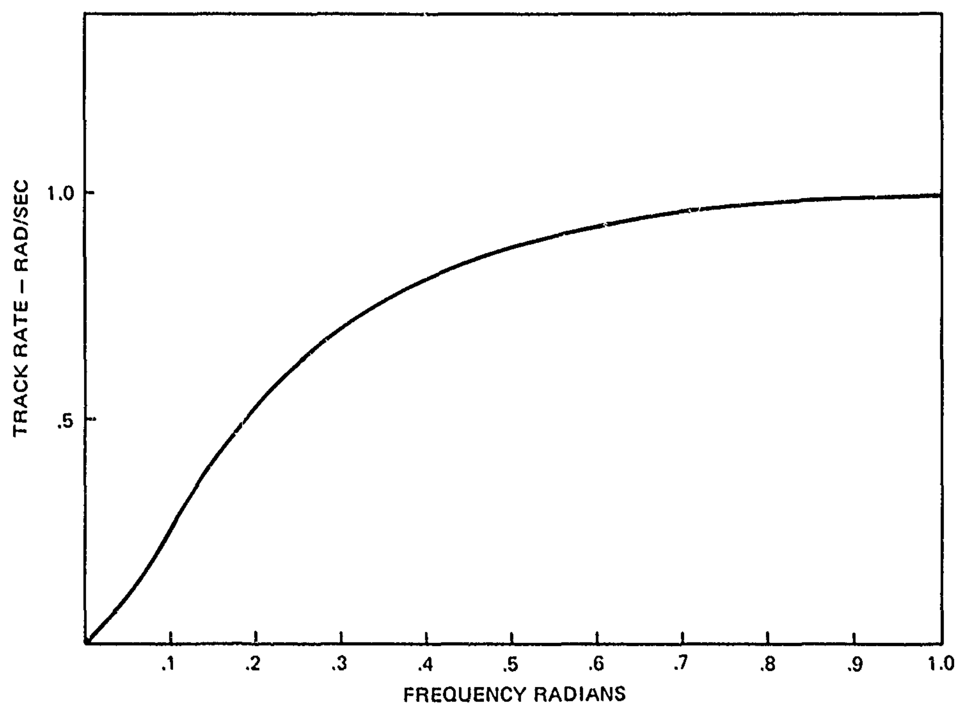

Figure 53. Track loop time response (outer gimbal).

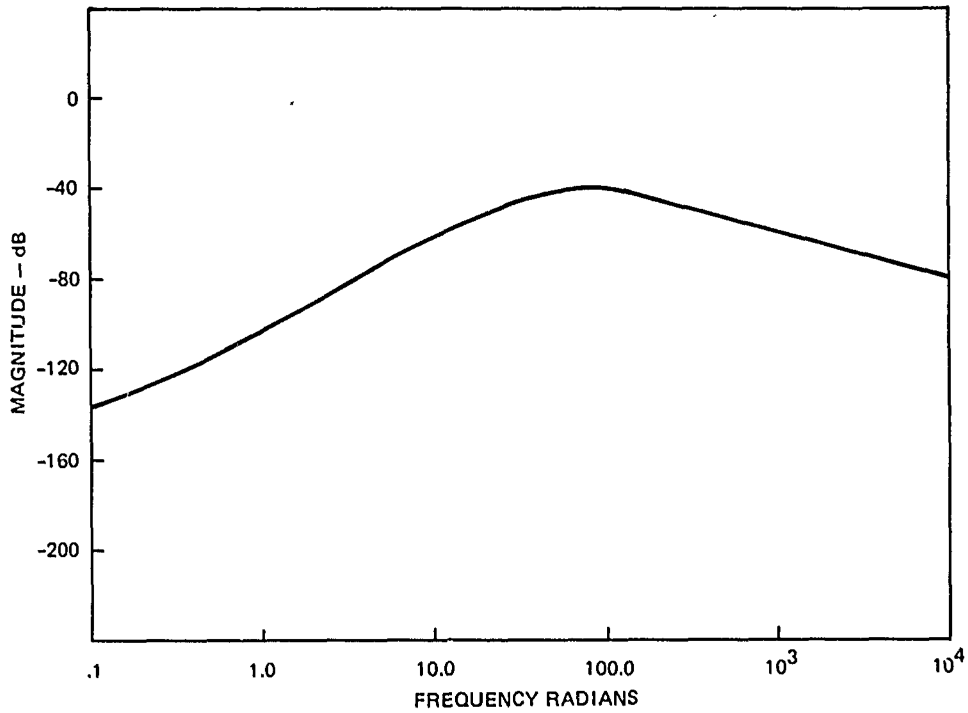

Figure 54. Frequency response of pointing error to body motion disturbance $\epsilon/\dot{\theta}$ (inner gimbal).

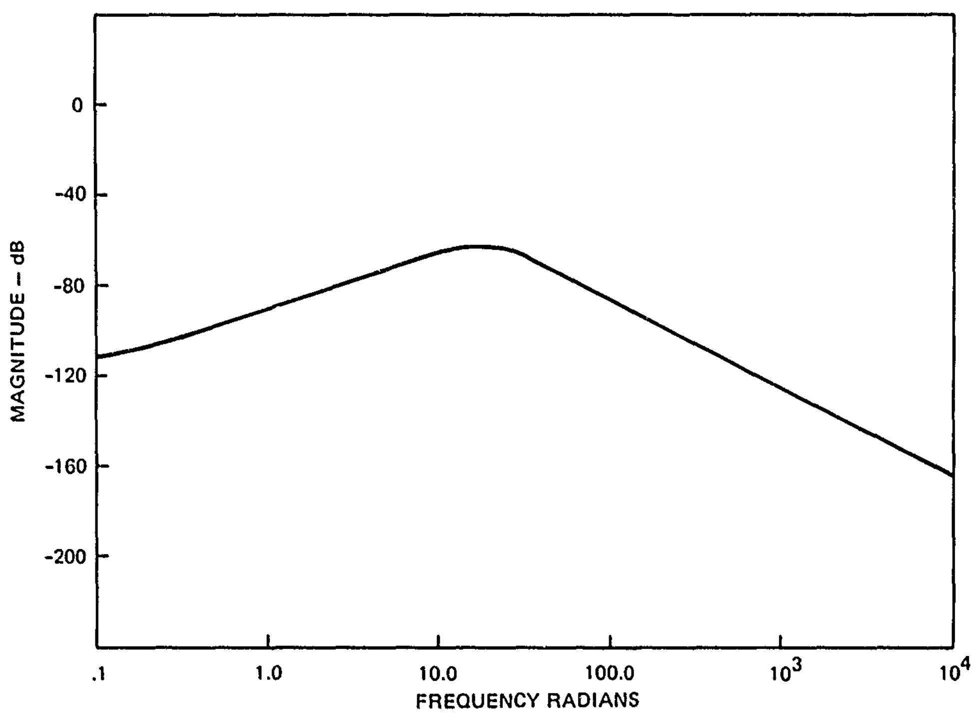

Figure 55. Frequency response of pointing error to torque disturbance ϵ/T_d (inner gimbal).

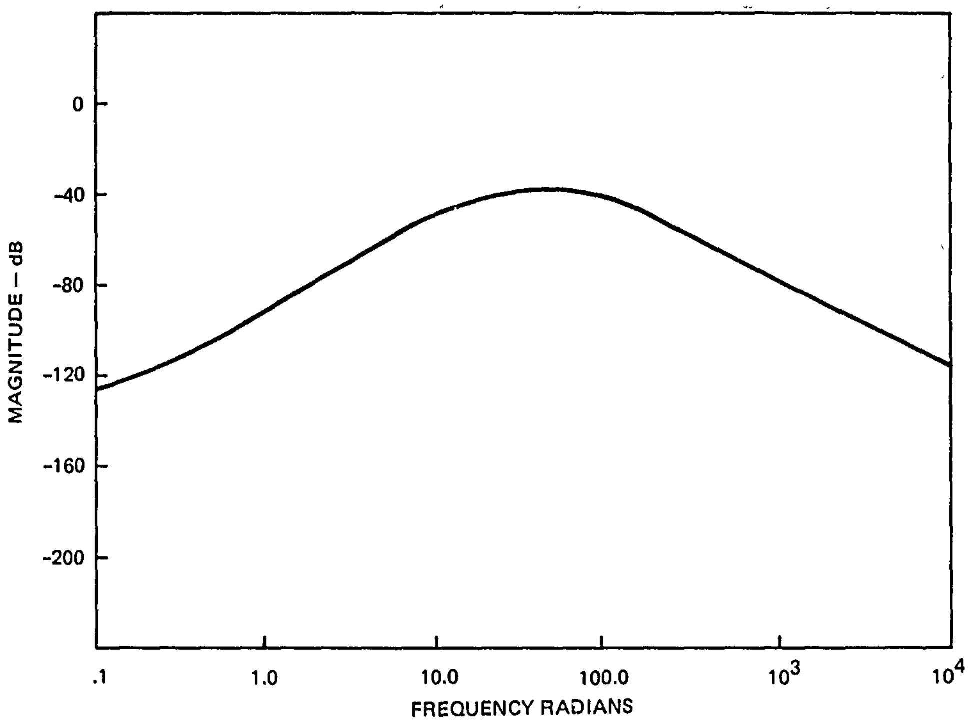

Figure 56. Frequency response of estimated line-of-sight to body motion disturbance $\hat{\dot{\sigma}}/\dot{\theta}$ (inner gimbal).

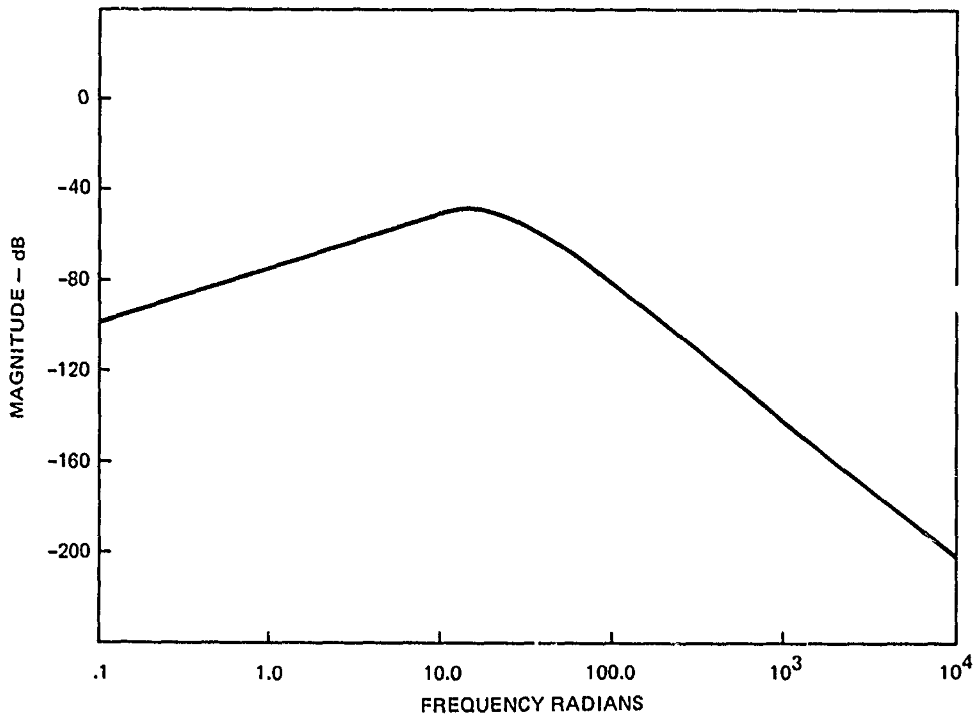

Figure 57. Frequency response of estimated line-of-sight to torque disturbance $\hat{\dot{\sigma}}/T_d$ (inner gimbal).

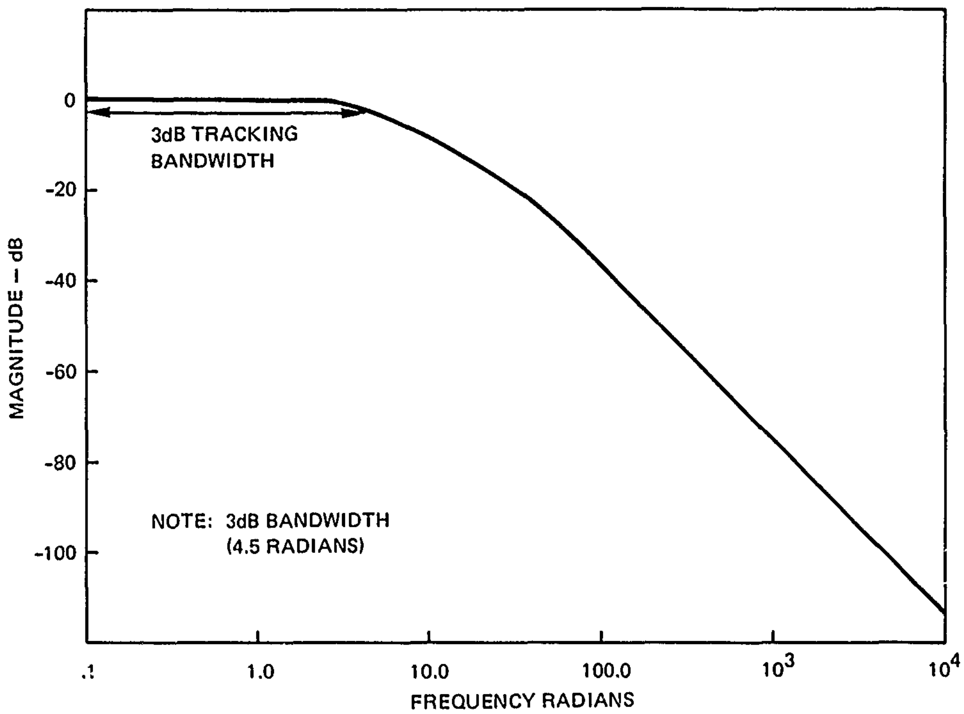

Figure 58. Frequency response of track loop $\hat{\dot{\sigma}}/\dot{\sigma}$ transfer function (inner gimbal).

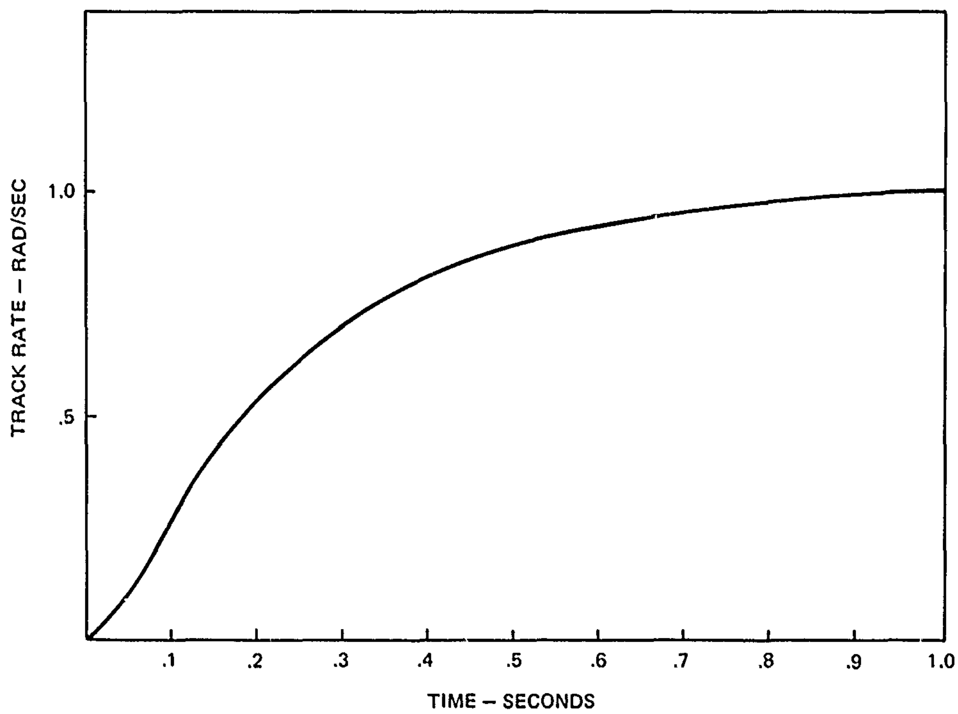

Figure 59. Track loop time response (inner gimbal).

5. SUMMARY

A stabilized sensor is required for modern day missile guidance applications. This is particularly essential for air-to-air guidance missiles. The stabilized sensor provides the following:

(1) An inertial reference from which line-of-sight rates can be measured.

(2) It decouples body motion and extraneous torque disturbances from the guidance signals.

(3) The target tracking sensor is maintained in an optimum boresight region of operation.

This report covers the design and development of such a space stabilized platform for a missile guidance or surveillance sensor. The design philosophy was based on a high torque-to-inertia ratio. This philosophy leads to a low cost system. The high torque-to-inertia system has excellent extraneous torque disturbance isolation. This allows higher tolerances on mass imbalances. It is the "Swiss watch" manufacturing process in the conventional space stabilized platforms which needed to be maintained to achieve the low mass imbalance requirements. Traditionally this Swiss watch type of manufacturing carries along with it high machining costs. Torque is essentially a cheap commodity. By maintaining higher torque level in the servo design, a design approach was established which led to overall lower system costs. In addition, the tracking and slew rate performance of the platform was greatly increased as a result of the high torque-to-inertia criterion.

The design performance of the platform is summarized in tables 5 through 7. Each table relates to a separate mode of operation or servo loop.

Figures 60 and 61 present the block diagrams of the finalized designs for the servo loops. Tables 8 and 9 present the values for the individual parameters shown in the block diagrams of figures 60 and 61. Figures 62 and 63 show the system hardware, ie, the antenna sensor mounted to the gimbal.

Design/Performance Parameters	Inner Gimbal	Outer Gimbal
Rise Time	0.014 sec	0.01 sec
Delay Time	0.011 sec	0.008 sec
Percent Overshoot	12.64%	10.7%
Settling Time	0.065 sec	0.05 sec
Velocity Error Constant	40 288.88 1/sec	46 482.4 1/sec
Bandwidth	250 rad	270 rad
M_P	4 dB	3 dB

Table 5. Slave loop design performance.

Design/Performance Parameters	Inner Gimbal	Outer Gimbal
Rise Time	0.002 sec	0.0025 sec
Delay Time	0.0015 sec	0.00175 sec
Percent Overshoot	28%	28%
Settling Time	0.06 sec	0.1 sec
Acceleration Error Constant	225 568.21/sec^2	300 040.44/sec^2
Bandwidth	750 rad	550 rad
M_P	3.2 dB	4 dB

Table 6. Stabilized loop design performance.

Design/Performance Parameters	Inner Gimbal (Isolation – dB Track Rate – deg/sec)	Outer Gimbal (Isolation – dB Track Rate – deg/sec)
Maximum Track Rate	143.24	114.6
Minimum Isolation:		
$\left.\frac{\hat{\dot{\sigma}}}{\dot{\theta}}\right\|_{S = 1;\ 10\ \text{rad/sec}}$	92; 48	90; 48
$\left.\frac{\hat{\dot{\sigma}}}{T_d}\right\|_{S = 1;\ 10\ \text{rad/sec}}$	75; 50	90; 66
$\left.\frac{\epsilon}{\dot{\theta}}\right\|_{S = 1;\ 10\ \text{rad/sec}}$	104; 60	100; 60
$\left.\frac{\epsilon}{T_d}\right\|_{S = 1;\ 10\ \text{rad/sec}}$	90; 64	106; 82

Table 7. Track loop design performance.

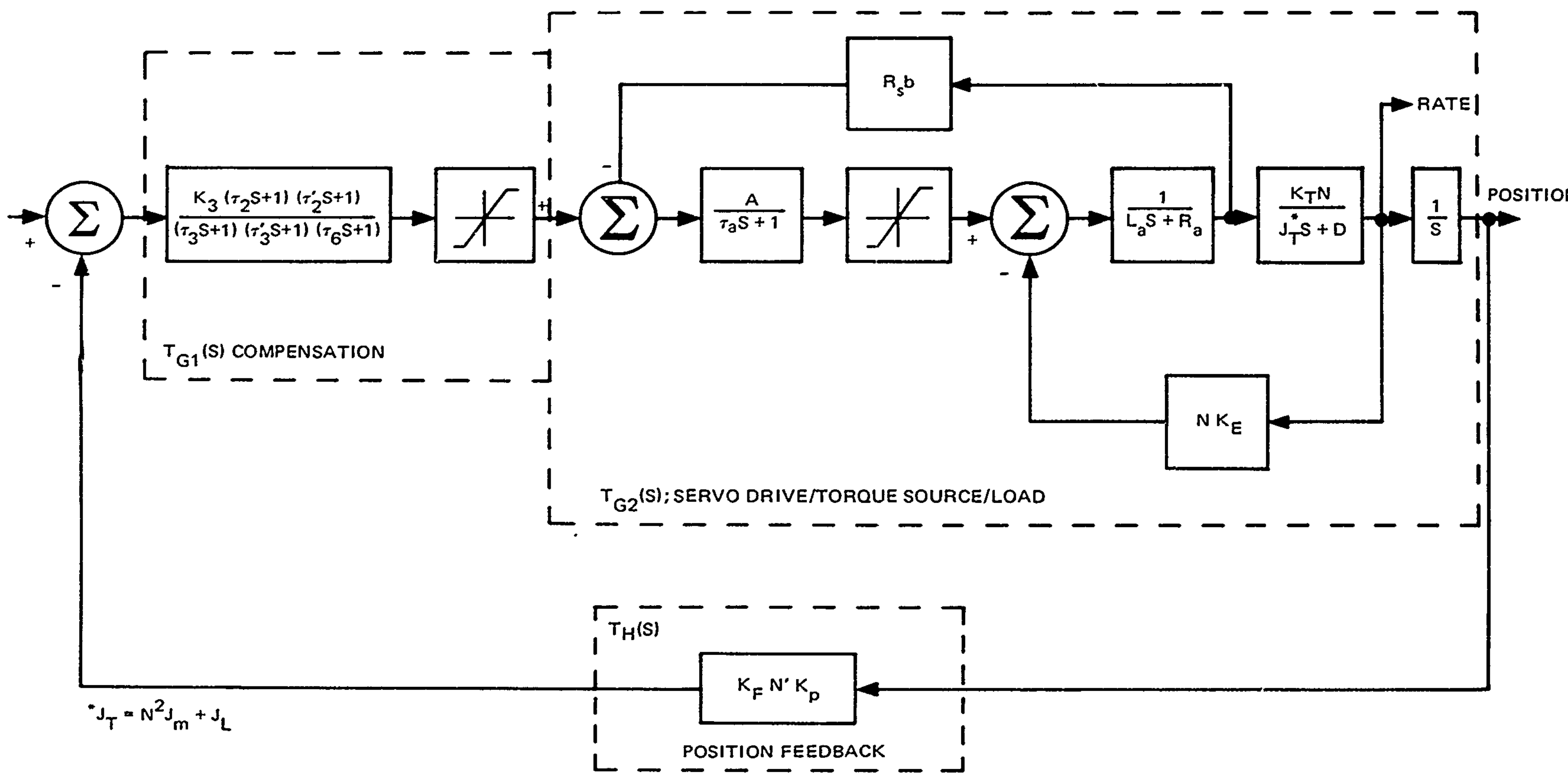

Figure 60. Sensor servo platform, slave loop.

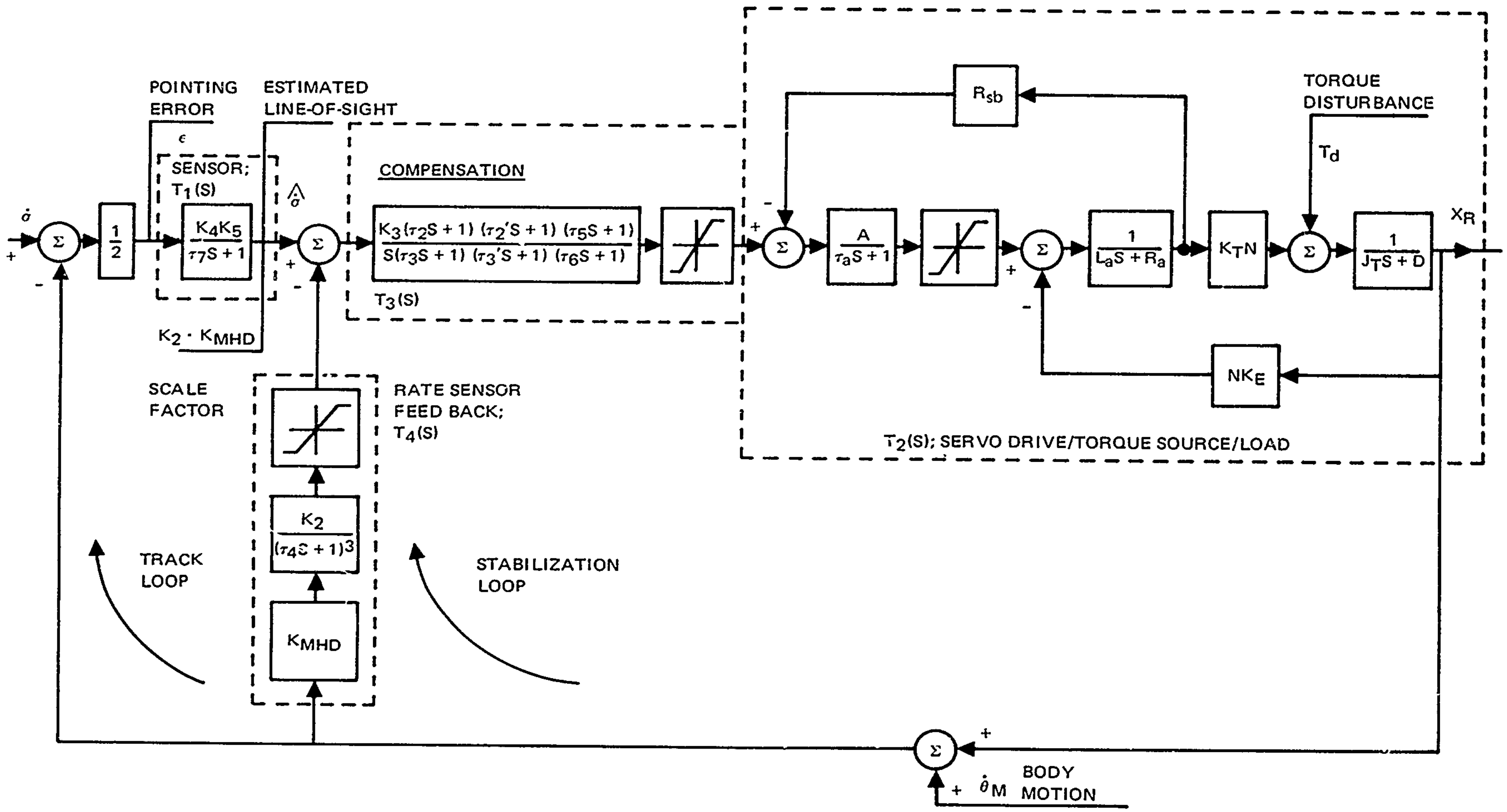

Figure 61. LADSS stabilized platform, stabilization/track loops.

Sensor:

Parameter	Units	Inner Gimbal	Outer Gimbal
K_4	Vdc/Vdc	7.0	7.0
K_5	Vdc/Rad/sec	7.0	7.0
τ_7	sec	.025	.025

Compensation Network:

Parameter	Units	Inner Gimbal	Outer Gimbal
K_3	Vdc/Vdc	46.68	84.72
τ_2	sec	.01	.01
τ_2'	sec	.01	.01
τ_5	sec	.1	.1
τ_3	sec	.0005	.0005
τ_3'	sec	.0005	.0005
τ_6	sec	.8	.8

Limiter: All limiters are ±20 volts.

Rate Sensor Feedback:

Parameter	Units	Inner Gimbal	Outer Gimbal
K_2	Vdc/Vrms	14.0	14.0
τ_4	sec	.0015	.0015
K_{mhd}	Vrms/Rad/sec	.8595	.8595

Servo Drive System: Same as those of slave loop of table 9.

Table 8. Stabilization track/loop parameter values.

Compensation Network:

Parameter	Units	Inner Gimbal	Outer Gimbal
K_3	Vdc/Vdc	4.668	5.086
τ_2	sec	.018	.0195
τ'_2	sec	.018	.0195
τ_3	sec	.0015	.0015
τ'_3	sec	.0015	.0015
τ_6	sec	.024	.020

Limiter: All limiters are ±20 volts.

Servo Drive/Torque Source/Load:
(These values are for slave and stabilization loops)

Parameter	Units	Inner Gimbal	Outer Gimbal
A	Vdc/Vdc	100 000.00	100 000.00
τ_a	sec	.02	.02
L_a	Millihenries	.0027	.0014
D	oz-in-sec	.622	.706
R_a	ohms	9.317	3.0
$R_s b$	ohms	1.0	1.0
J_m	oz-in-sec^2	.0015	.016
J_L	oz-in-sec^2	2.47	3.30
K_T	oz-in/amp	19.75	24.6
N	Gear ratio	12.8	8.5
K_E	Vdc/rad/sec	.141	.177

Position Feedback:

Parameter	Units	Inner Gimbal	Outer Gimbal
K_F	Vdc/Vdc	1.5	2.295
N	Pot gear ratio	3.0	8.5
K_p	Vdc/rad	4.776	1.592

Table 9. Slave loop parameter values.

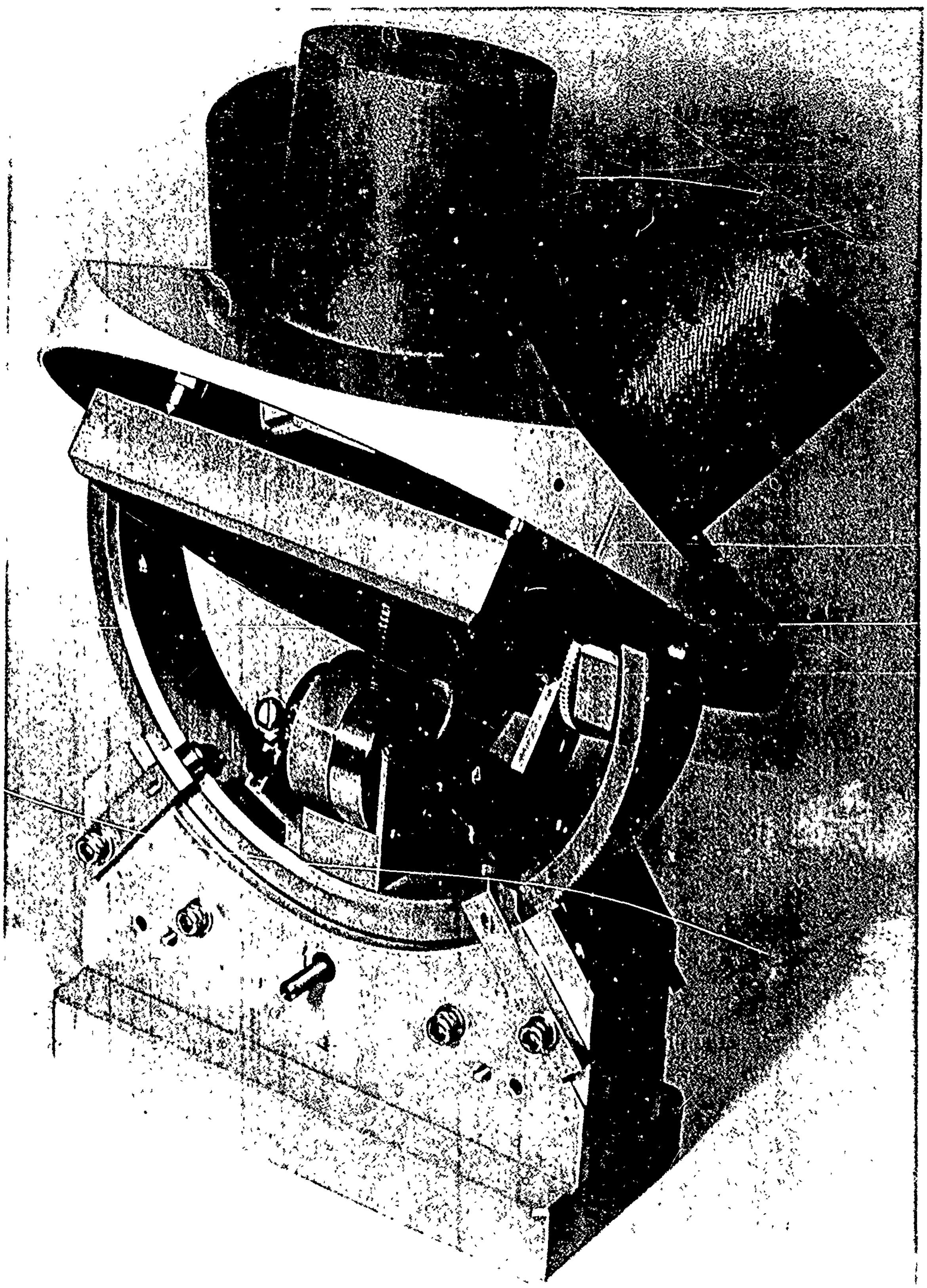

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Figure 62 Stabilization platform/sensor system showing outer and inner gimbal.

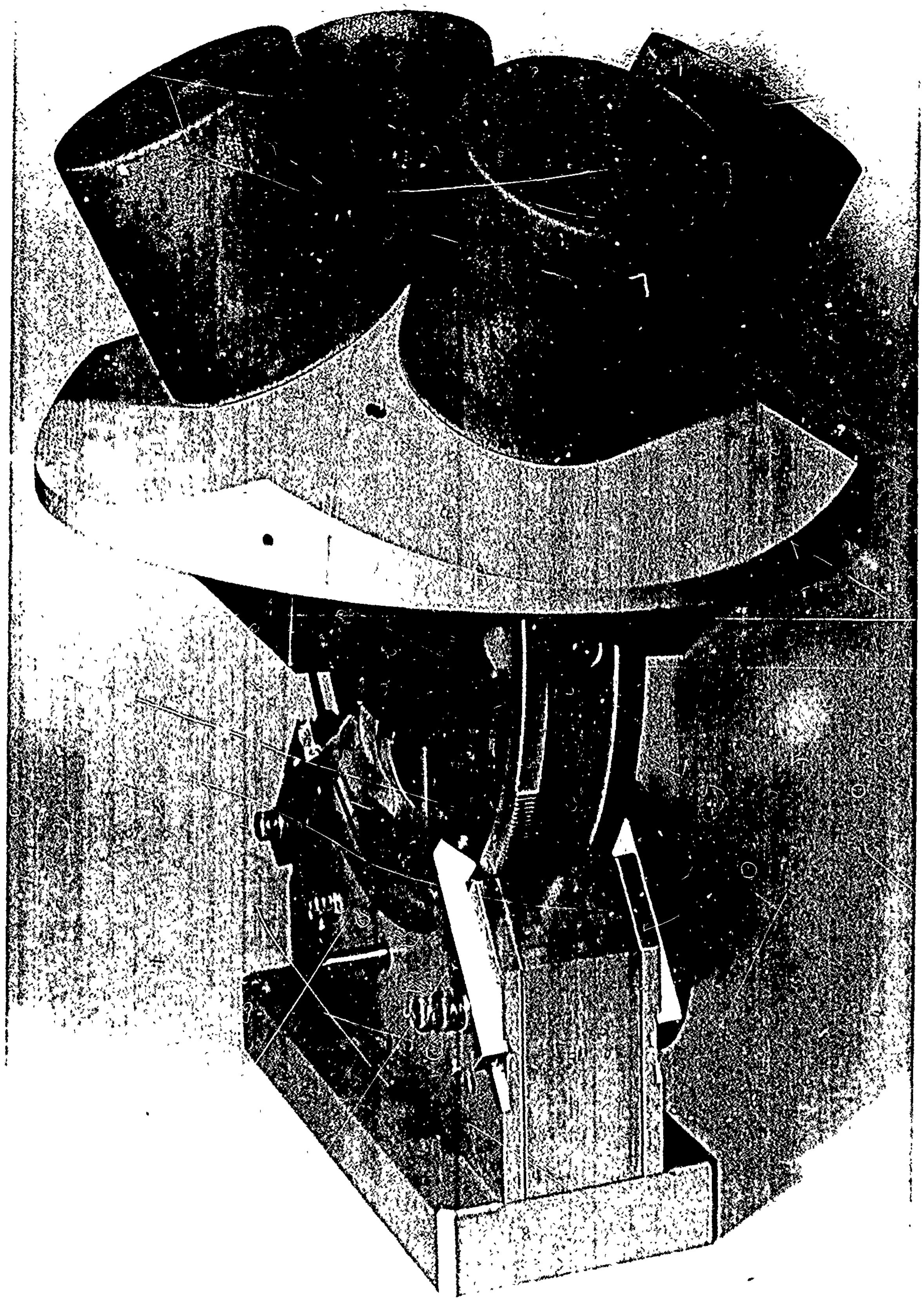

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Figure 63 Stabilizing platform and sensor mounted to stable platform.

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APPENDIX A
TECHNICAL DESCRIPTION OF RATE SENSOR

This appendix is essentially a reprint of technical product data supplied to NOSC by Honeywell.* The technical description in this appendix covers the Honeywell GG 2500 rate sensor and the readout electronics (demodulator and filters) associated with the rate sensor.

*Honeywell, Avionics Division, Minneapolis, Minnesota, GG2500 MHD (Magnetohydrodynamic) Two-Axis Rate Sensor, February 1978

SECTION I

GG2500 MHD (MAGNETOHYDRODYNAMIC) TWO-AXIS RATE SENSOR

The Honeywell GG2500 is a new concept subminiature, high performance, two-axis rate sensor specifically designed for large volume producibility. It has been qualified to environmental requirements of MIL-STD-810B for gyros installed in airplanes, helicopters, and air and ground launched missiles. It is ideally suited for tactical missile seekerhead stabilization, aircraft and missile autopilot application, and rate measuring for fire control systems.

Direct benefits to the user are:

- Subminiature size and weight; two-axis information from a unit only one-fourth the volume of two conventional rate gyros
- Excellent Linearity (< 0.1% FS)
- Negligible Hysteresis (<0.01 deg/sec)
- Low Temperature-Sensitivity
- Low G-Sensitivity
- Wide Dynamic Range (10^6)
- Frequency Response Independent of Temperature
- Over-Rate Capability 20,000 deg/sec

SECTION II
PERFORMANCE

The performance characteristics of the GG2500 are listed in Table 1. These characteristics, unless specified otherwise, apply for any of the environments shown in the table.

Table 1. MHD Rate Sensor Specifications (GG2500LC02 and GG2500LC03)

Parameter	Performance
Scale Factor	GG2500LC02: 15 ± 5% mV rms/deg/sec GG2500LC03: 15 ± 1% mV rms/deg/sec
Zero Rate Error (includes run-up repeats)	GG2500LC02: 0.5 deg/sec max. GG2500LC03: 0.15 deg/sec max.
Linearity	0.1% of max. rate (max. dev. from best STR line)
Cross Coupling (axis change vs. input rate)	0.5% of full scale (max. dev. from best STR line)(1)
Hysteresis	0.01 deg/sec max.
Threshold	0.01 deg/sec max.
Acceleration Sensitivity	0.05 deg/sec/g max.
g^2 Sensitivity	1×10^{-3} deg/sec/g^2 max.
Output Noise at Null	100 mV rms max. (using 1000-Hz bandwidth meter)
Rate Input Range	To ±480 deg/sec
Frequency Response	100 Hz min. without electronics
Ref. Gen. Output	1 V rms min. each axis
Ref. Gen. Phase Angle	90 ± 0.5 degrees
Performance Stability with Environments	
Zero Rate Error Stability over all Environments	0.15 deg/sec
Acceleration Sensitivity Stability over all Environments	0.03 deg/sec/g
Scale Factor Change - vs - Temperature	±2%
Input Axis Change - vs - Temperature	±0.5 deg
Excitation Requirements	
Motor	26 ± 2 volt rms 400 Hz 2Ø, 4 watts max.
Preamp	±15 ± 3 Vdc, 4 mA max. with 500 mV max. p-p ripple
Weight	70 grams max.

(1) When operated with amplifier-demodulator readout electronics. Deviation is expressed as a percent of opposite axis full scale.

SECTION III
ENVIRONMENTAL CAPABILITY

The GG2500 is designed to meet or exceed environmental requirements of MIL-STD-810B as it applies to gyros intended for installation in aircraft, helicopters, and air and ground launched missiles; and has been successfully qualified to the environmental levels listed in Table 2. Performance before, during, and after each exposure has been measured; these results have been used to establish performance capability. See Figures 1 and 2 for the installation drawing and sensor schematic.

Table 2. Environments

Environments	Limits
Overrange Capability	20,000 deg/sec
Temperature Operating Non-Operating	 -65°F to +160°F -65°F to +220°F
Altitude	MIL-STD-810B, Method 500, Proc II to 60,000 Ft.
Temperature Shock	MIL-STD-810, Method 503, Proc 1 + 71°C to -54°C to +71°C, four (4) hours each temp -5 minutes between chambers.
Vibration	MIL-STD-810, Method 514, Proc II 2 hr/axis - Time Schedule V of Table 514-II, Curve H (10 G Peak Sine) 1/2 hr/axis - Time Schedule II of Table 514-II, Curve Q (10 G Peak Sine) 1/2 hr/axis - Time Schedule II of Table 514-II, Curves AH (11.9 G RMS Random) and AK (20.7 G RMS Random)
Shock	2 drops/axis each direction, 12 drops total each level: 40 G, 18 MS; 400 G, 1.5 MS; 100 G, 6 MS; 500 G, 0.75 MS; MIL-STD-810, Method 516, Proc IV
Acceleration	100 G, each direction - each axis
Magnetic Sensitivity	.05 deg/sec/gauss max
EMI Susceptability	MIL-STD-461
Useful Life	Life tested to 1000 hours

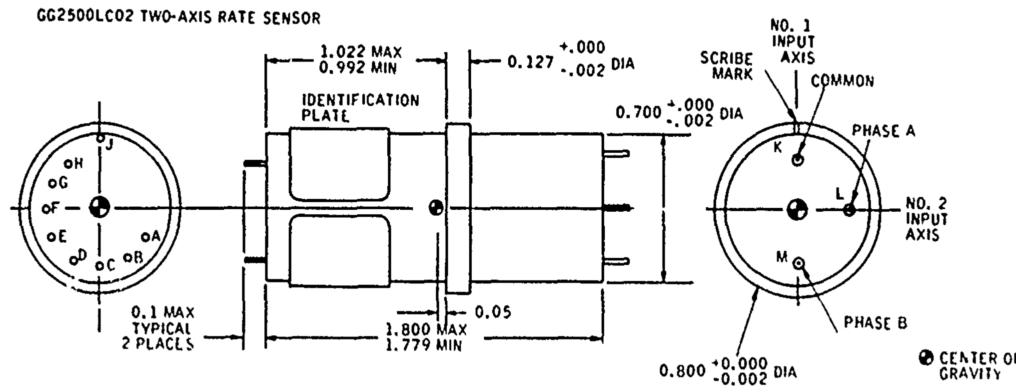
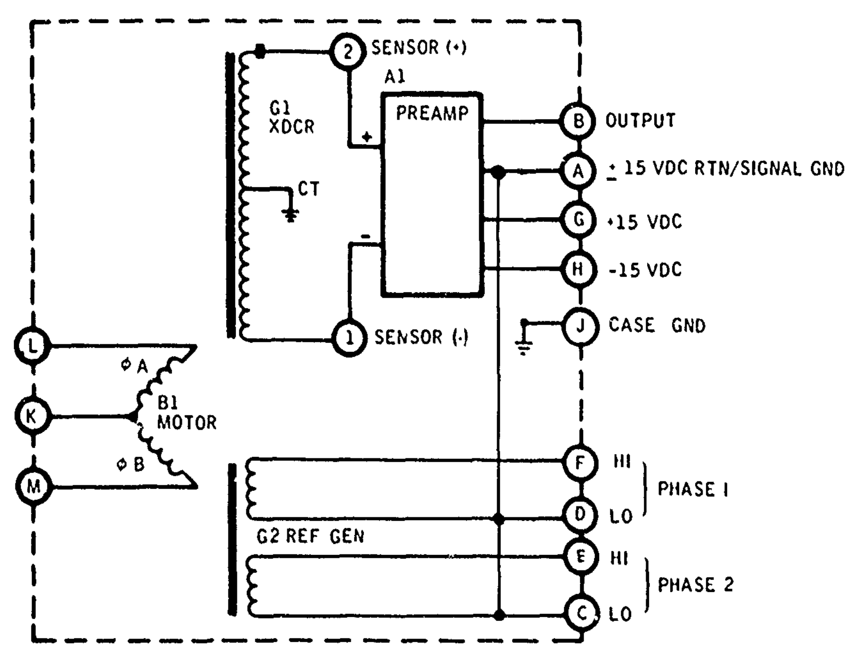


Figure 1. Installation Drawing



TERMINALS 1 & 2 ARE NOT ACCESSIBLE

Figure 2. Sensor Schematic

SECTION IV
TECHNICAL DESCRIPTION

OPERATING PRINCIPLE

The GG2500 Rate Sensor is a non-gyro sensor; it does not depend on the momentum of a spinning wheel for operation. An angular accelerometer is used in the basic sensor. By rotating the accelerometer at a constant speed about an axis perpendicular to its input axis, an input rate in a plane normal to the spin axis is changed to a time varying angular acceleration that is sensed by the accelerometer.

To obtain further insight into the operation, consider an angular accelerometer that is being rotated at a constant rate, W_S, about an axis perpendicular to the angular accelerometer input axis. If a rate exists perpendicular to this rotation axis, the instantaneous rate about the angular accelerometer input axis is:

$$\omega_o = \omega_x \sin \omega_s t \quad \text{(see Figure 3)}$$

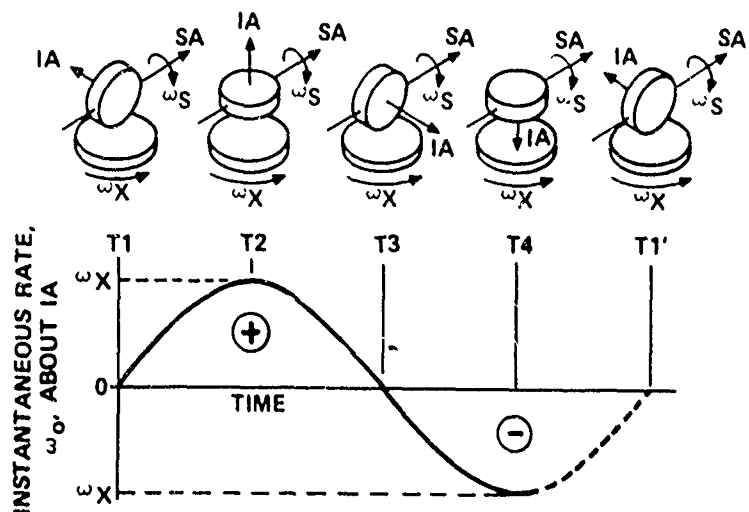


Figure 3. MHD Theory of Operation

The angular acceleration about the input axis, therefore, is:

$$\dot{\omega}_o = \frac{d\omega_o}{dt} = \omega_s \omega_x \cos \omega_s t$$

By these means the input rate is changed to a time-varying angular acceleration. The rotating accelerometer acts as an integrator that provides an ac output voltage, which is directly proportional to rate, at a frequency equal to the rotation frequency.

PHYSICAL CONSTRUCTION

A cross section of the complete rate sensor is shown in Figure 4. The sensor consists of the angular accelerometer, a hysteresis-synchronous drive motor, a two-phase reference generator, a slip ring assembly to transfer the accelerometer output signal from the rotating element, and an integrally mounted accelerometer preamplifier. The entire sensor is fabricated from a high permeability nickel iron alloy that serves as an effective magnetic shield. Laser welding of all internal and external joints ensures structural integrity and hermaticity under severe environments.

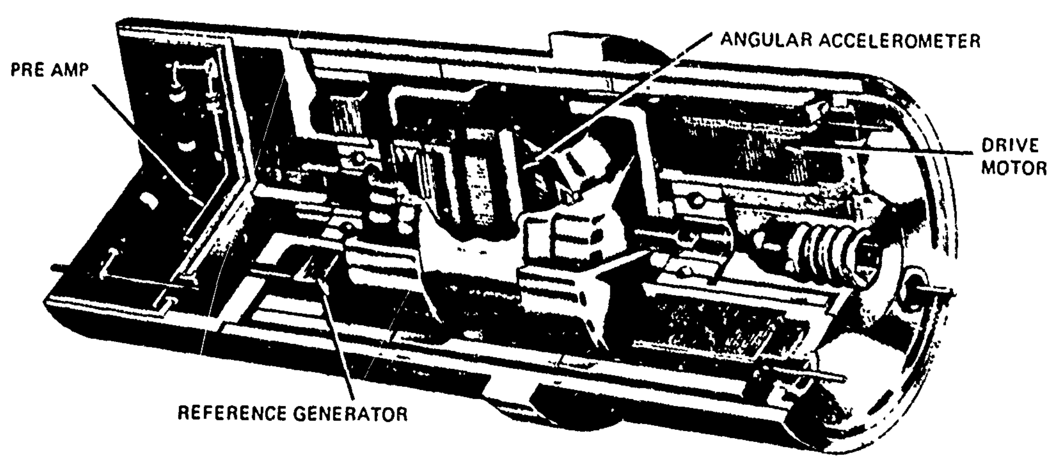


Figure 4. GG2500 Rate Sensor

MOTOR DESIGN

The rotor drive is a two-phase hysteresis synchronous motor wound to operate with an excitation of 26 V at 400 Hz. Since the stator is attached directly to the rate sensor case, it does not enter into the dynamics of rotor balance and mass stability as in a conventional gyro. In addition, the heat generated in the motor windings is conducted directly to the sensor mounting surfaces without passing through the rotor bearings, thus minimizing motor temperature rise and thermal gradients across the sensor.

REFERENCE GENERATOR

The two-phase reference generator provides the demodulator reference signals to permit the composite rate signal to be resolved into two-axis information. The stator is positioned on the rotor spin axis and is wound in a standard two-phase configuration. A diametrically charged ring magnet attached to the rotor provides the lines of flux required to generate a voltage in each winding. The reference generator output, when loaded with a 10K or greater resistive load, is greater than 1.0 V rms at the rotor frequency of 200 Hz.

ANGULAR ACCELEROMETER

The angular accelerometer used in the device is depicted in Figure 5. An annular ring of mercury exists between the radially oriented permanent magnet and the magnetic case, which provides the magnetic path. The existence of a rate input results in a relative motion of the magnetic field with respect to the mercury. This motion through the phenomonen of magnetohydrodynamics (MHD) causes a voltage gradient across the mercury at right angles to the magnetic field and the relative motion. Contacts on either side

of the mercury ring provide a single turn primary for the transformer. The voltage generated across the mercury causes a current to flow through the single turn primary, which, in turn induces a corresponding voltage in the secondary winding.

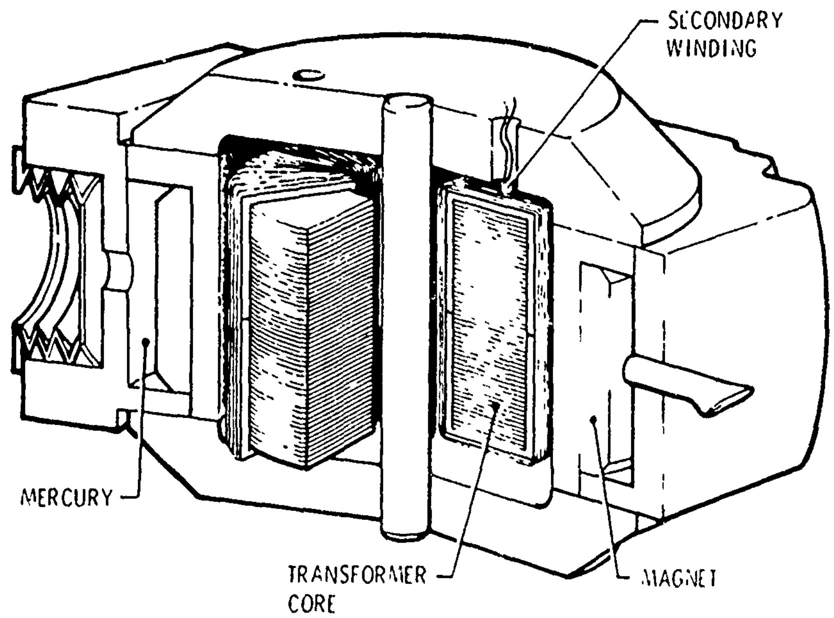


Figure 5. Angular Accelerometer

The voltage induced in the mercury is:

$$E = B\,l\,v$$

where

B	=	flux density
l	=	length of moving conductor
v	=	velocity of conductor relative to the magnetic field

In terms of angular velocity:

$$e = B\,l\,\omega_r r$$

where

r = mean radius of the mercury

ω_r = angular velocity of the mercury relative to the magnetic field (or sensor case)

To determine the relationship between ω_r and the input angular rate ω_o, the open-loop transfer function for the angular accelerometer is examined:

$$\omega_r = \omega_o \left(\frac{\frac{I}{C} S}{\frac{I}{C} S+1} \right)$$

where

ω_r = angular velocity of the mercury relative to the magnetic (or sensor case)

ω_o = angular input to case

I = polar moment of inertia of mercury

C = damping of mercury

S = La Place operator

In the practical case where $\left| \frac{I}{C} S \right|$ is much greater than one, the quantity within the parenthesis is unity to within one part in 10^7. This means that the input rate and the rate between the magnetic field and the mercury are essentially identical and that the mercury is motionless about its input axis. Thus, the output of the MHD rate sensor is a true representation of the input rate.

Since both I and C are essentially constants over the operating temperature range, a method of temperature control to hold these parameters is not necessary.

ROTOR SUSPENSION

The rotor is mounted on two preloaded miniature precision ball bearings. Since the entire rotor and case structure are made from the same material, preload does not change as a function of ambient temperature changes. In a conventional gyro, mass balance instability can be caused by migration of lubricant from the rotor bearing, so lubrication is kept to an absolute minimum. Because the GG2500 does not operate by measuring precession torques, oil migration does not cause performance errors, so the lubricant can be applied copiously. The large amount of lubricant, coupled with inner race rotation and light loads, ensures long bearing life and stable device performance.

SLIP RING ASSEMBLY

The slip ring assembly is mounted on the rotor axis and, in conjunction with a case mounted brush block assembly, provides the means of coupling the accelerometer output signal to the preamplifier. Multiple brushes for each circuit result in extremely low contact resistance and noise free operation. Slip ring life tests have proven an operating life of greater than 2000 hours without degradation or any increase in contact resistance or slip ring noise.

PREAMPLIFIER ASSEMBLY

A thick-film hybrid circuit preamplifier is mounted integrally to the GG2500 Rate Sensor. This preamplifier functions as an interface between the low-level high-impedance sensor output and the external readout electronics. The input circuit of the preamplifier consists of a dual FET follower stage chosen for reasons of very low bias current (10 na) to minimize noise effects from slip ring resistance and dc offsets in the transformer core. The dual

FET stage drives an integrated circuit operational amplifier connected as a conventional non-inverting amplifier which furnishes the high-level low impedance output. The preamplifier assembly provides for scale factor and zero rate error (ZRE) calibration. A scale factor temperature compensation network has also been added to the preamplifier assembly.

A schematic of the GG2500 Rate Sensor is shown in Figure 2.

SECTION V
READOUT ELECTRONICS

A dual-channel demodulator is required to resolve the output of the GG2500 Rate Sensor into two-axes of information. In addition, some filtering is required to shape the response characteristics of the device.

A block diagram of the Honeywell circuits is shown in Figure 6. The circuit consists of an input band-pass filter and demodulator driver amplifier, reference signal driver amplifiers, a two-channel demodulator, and third-order low-pass output filters.

Honeywell is in the final stages of developing a miniature readout electronics package (shown in Figure 7) using thick-film hybrid packaging techniques. Honeywell expects to fully qualify this package to the GG2500 Rate Sensor qualification levels and have it available for delivery in the last half of 1978.

Initially, the EG1030AD will be available in the following gains, and resultant full scale ranges when used with the GG2500 Rate Sensor:

Gain Vdc/V rms	Full Scale Range Deg/sec
5.8	57.3
3.33	100
1.11	300
.9	370

Two versions of the output filter will be available; one with a 70-Hz bandwidth, the other with a 100-Hz bandwidth. The amplitude and phase

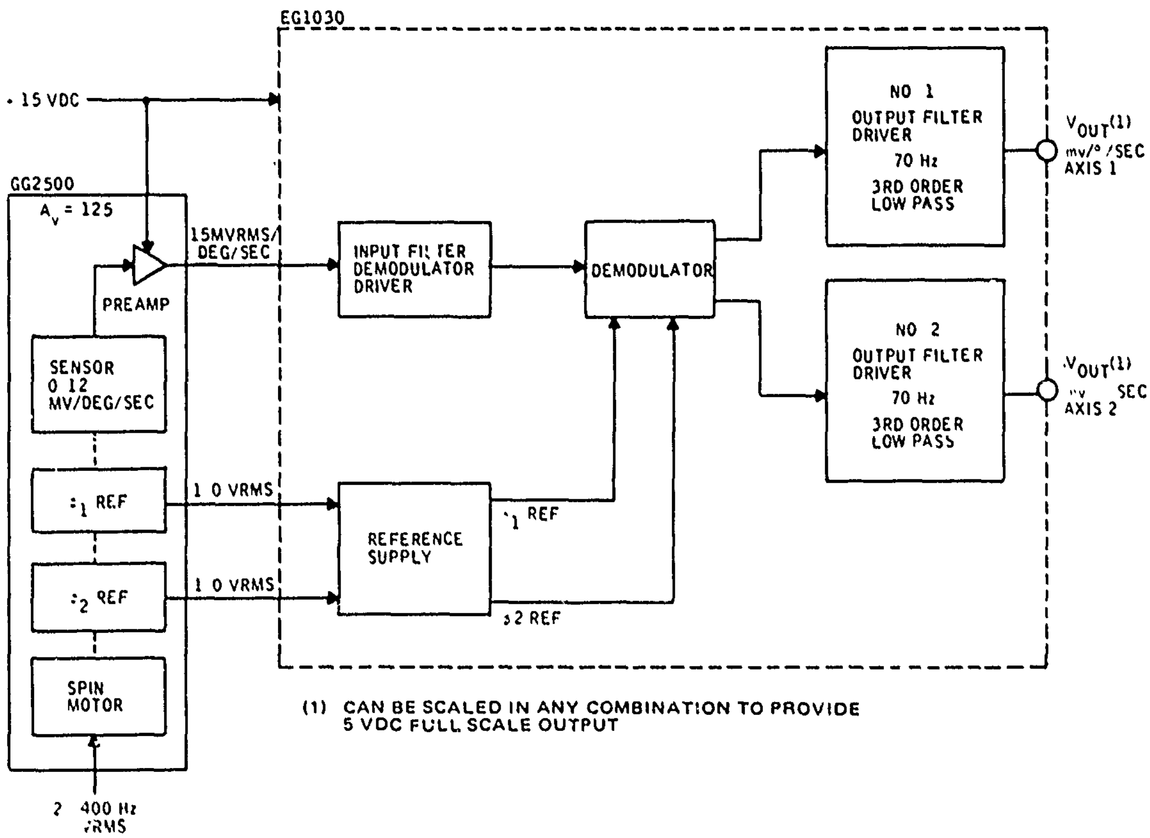


Figure 6. Block Diagram - GG2500LC Rate Sensor/ EG1030AD Amplifier Demodulator Readout Electronics.

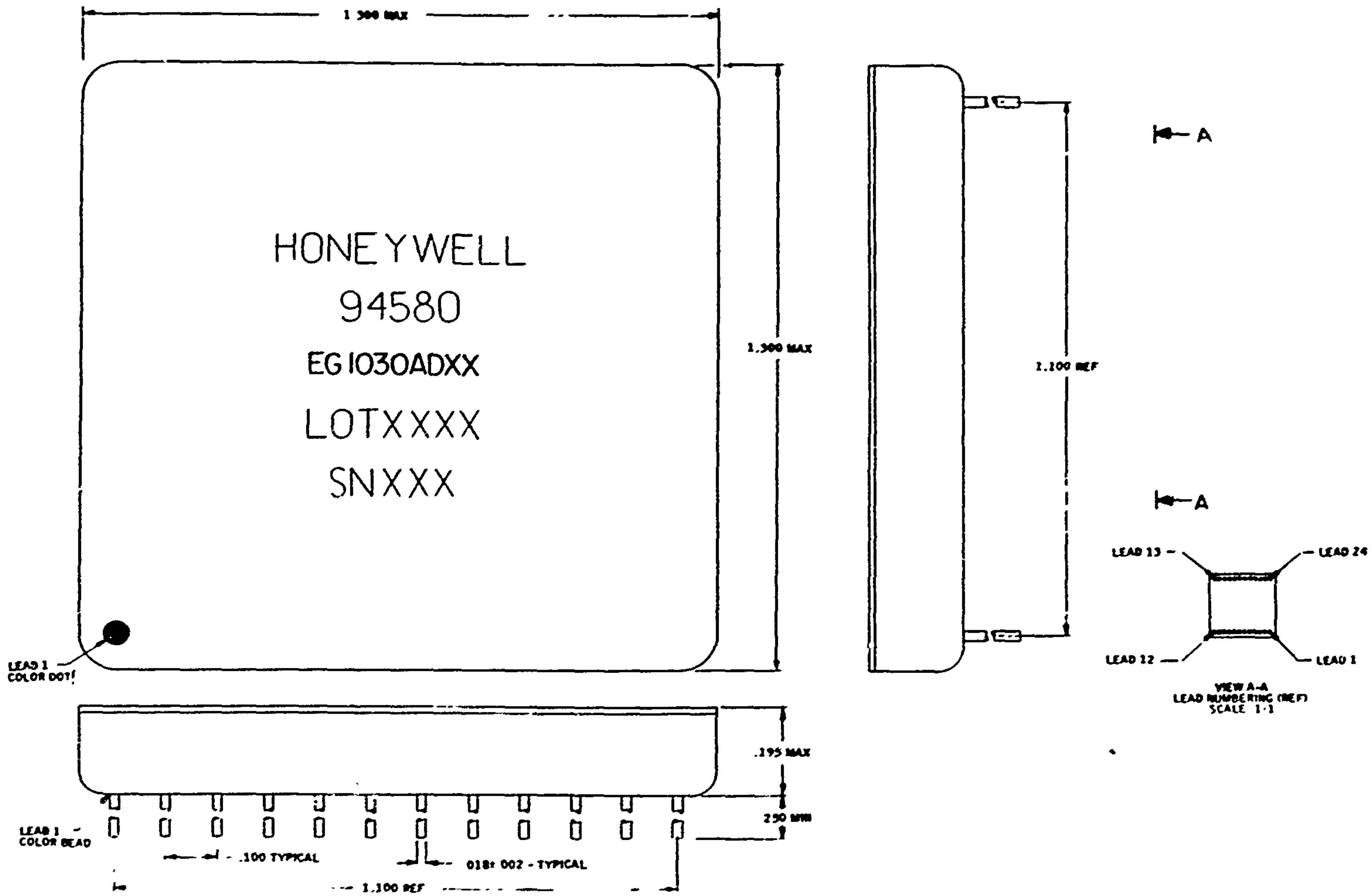


Figure 7. EG1030AD Outline Drawing

responses for these filters when used with a GG2500 Rate Sensor are shown in Figures 8 and 9.

The performance listed in Table 3 has been achieved using discrete components. It is expected that comparable performance will be realized with the thick-film circuitry. The quoted performance is for the EG1030AD when tested as a unit and does not include the contributions of the GG2500 MHD.

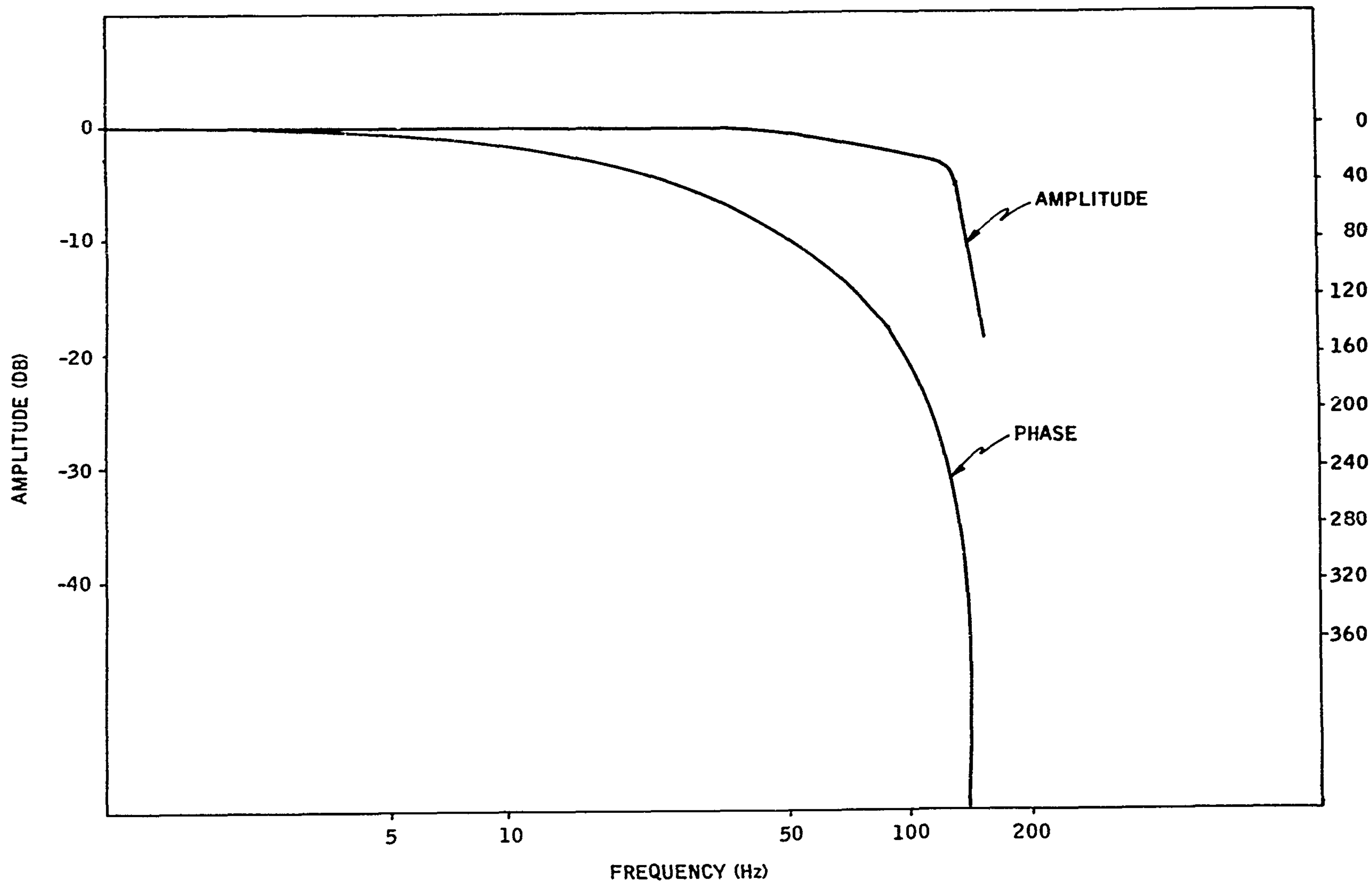


Figure 8. Amplitude and Phase Response - CG2500/ EG1030 (100 Hz Output Filter)

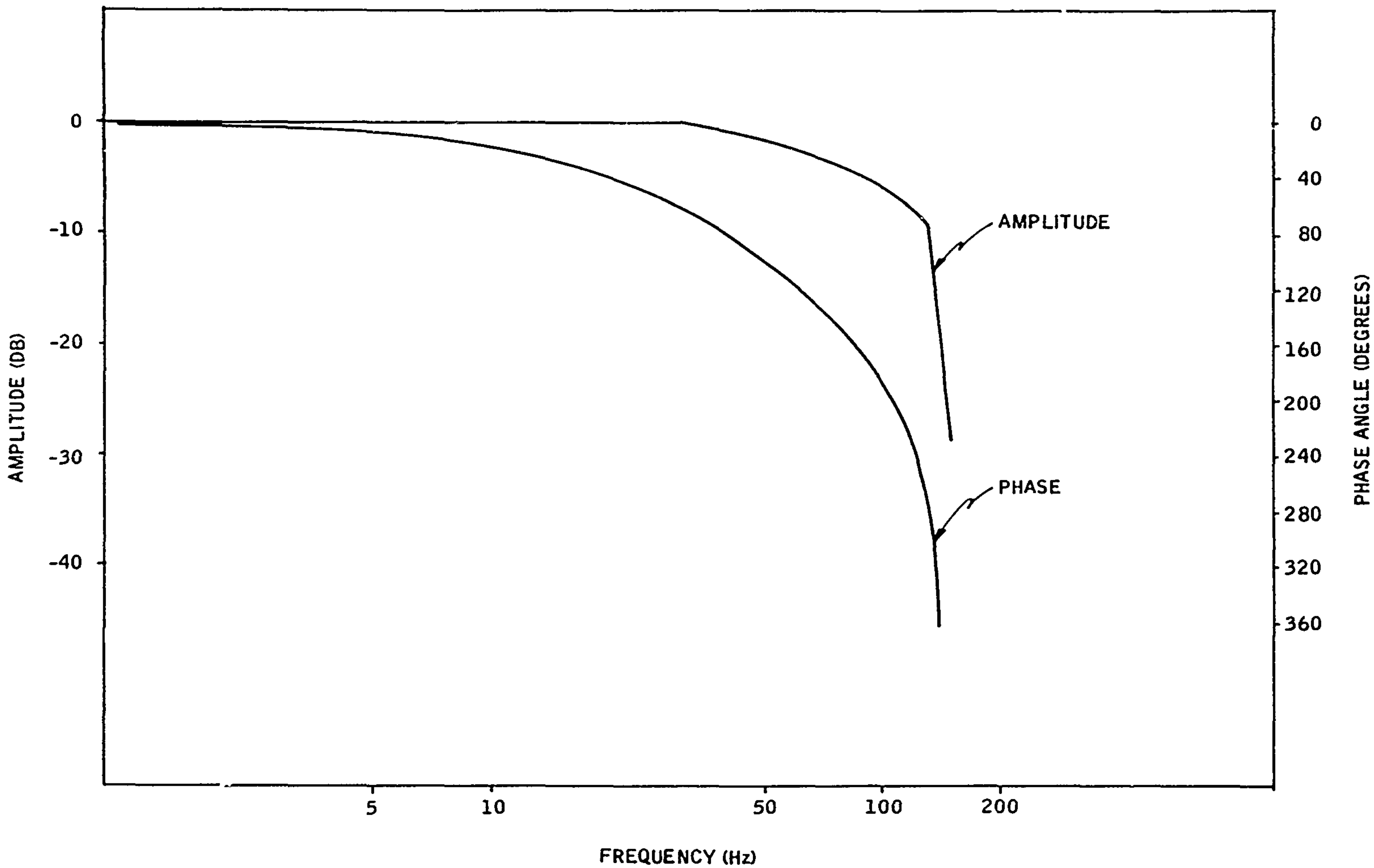


Figure 9. Amplitude and Phase Response - GG2500/ EG1030 (70 Hz Output Filter)

Table 3. EG1030 Miniature Amplifier-Demodulator Projected Performance

Parameter	Projected Performance
Supply Voltage	±15 ±3Vdc
Supply Current	15 mA at 60% F. S.
Output Range	±5 Vdc min.
Gain Set	±1% max.
Gain Stability (OTR)	±1% max. deviation
Offset	±1 mV max.
Offset Stability (OTR)	±0. 10 deg/sec max. @ 5. 8 gain ±0. 10 deg/sec max. @ 3. 33 gain ±0. 15 deg/sec max. @ 1. 11 gain
Linearity	±0. 03% of F. S. (Max DEV from best STR line)
Cross coupling	±0. 10% of F. S. (Max DEV from best STR line)(1)
Phase Angle (OTR)	±0. 15 deg. max. deviation(2)
Output Noise	
Input Shorted At 60% F. S.	2 mV rms 50 mV rms
Operating Temperature	-65°F to +200°F
Frequency Response	-3 dB @ 70 Hz or -3 dB @ 100 Hz
Dynamic Output Impedance	Less Than 1 ohm
Weight	16 grams

(1) Deviation is expressed as a percent of opposite channel full scale.

(2) This parameter represents the change in the phase relationship between the signal and the reference voltages at the input to the demodulators.

SECTION VI
SUPPORTIVE DATA

Typical data is presented to support and/or supplement the performance which was specified in Table 1.

FREQUENCY RESPONSE

The GG2500 is a wide-response device with an equivalent natural frequency of well beyond 100 Hz. The amplitude and phase response for the GG2500 is shown in Figure 10. It will be noted that as the input frequency approaches the spin frequency (200 Hz) there is considerable peaking before the output falls off to zero at 200 Hz. Therefore, Honeywell uses a third-order filter at the output of the amplifier-demodulator readout electronics to eliminate the peaking and yet at the same time maintain the maximum bandwidth. The amplitude and phase response for the combination of the GG2500 Rate Sensor and the EG1030 Amplifier-Demodulator Readout Electronics has previously been shown in Figure 8 for a 70-Hz filter and in Figure 9 for a 100-Hz filter.

SHORT-TERM ZRE STABILITY

A recording of the zero rate error (ZRE) from both channels over a 10-minute time period is shown in Figure 11. The maximum peak-to-peak excursion for either channel over the 10-minute time interval is 0.02 degree per second.

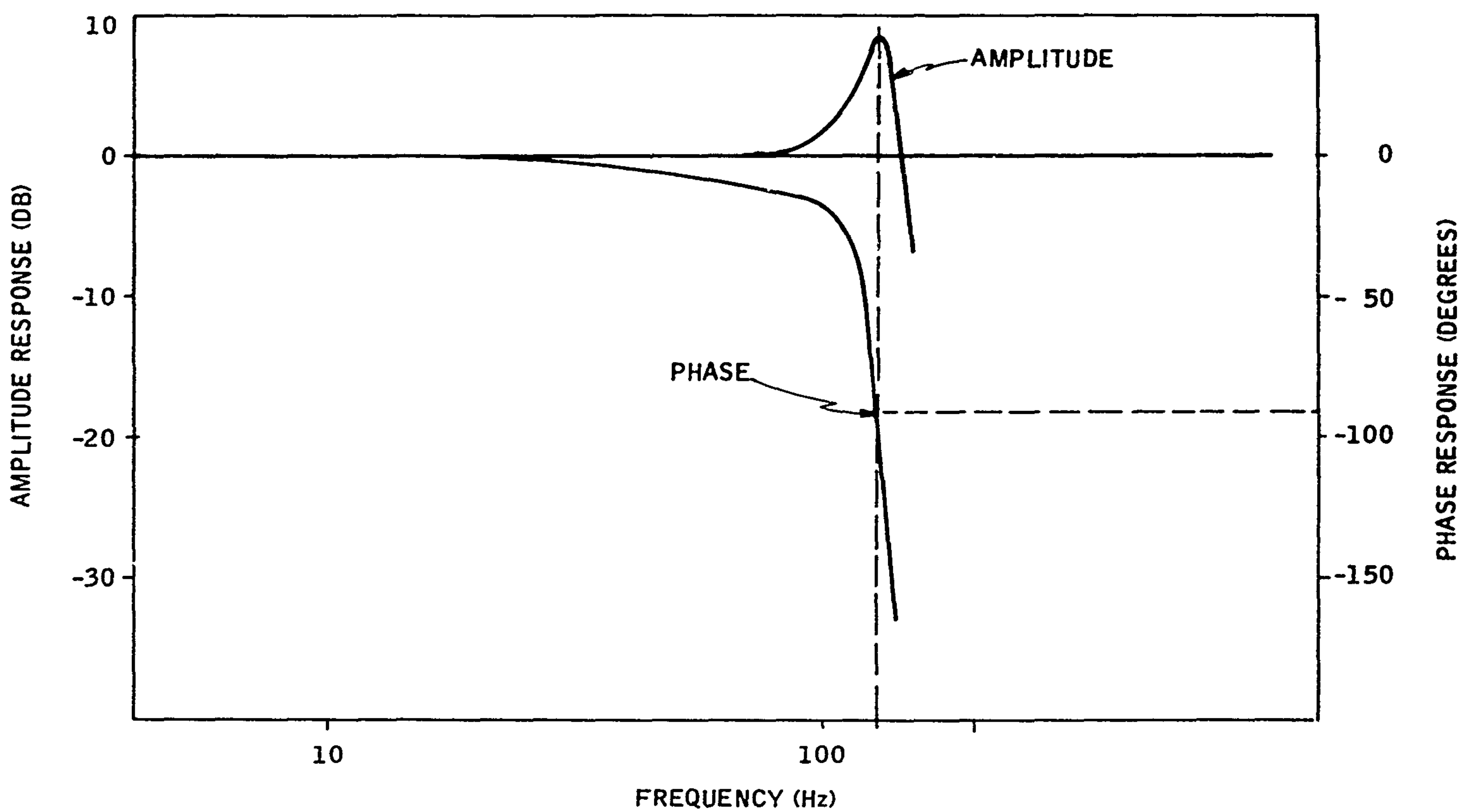


Figure 10. Amplitude and Phase Response - GG2500 MHD

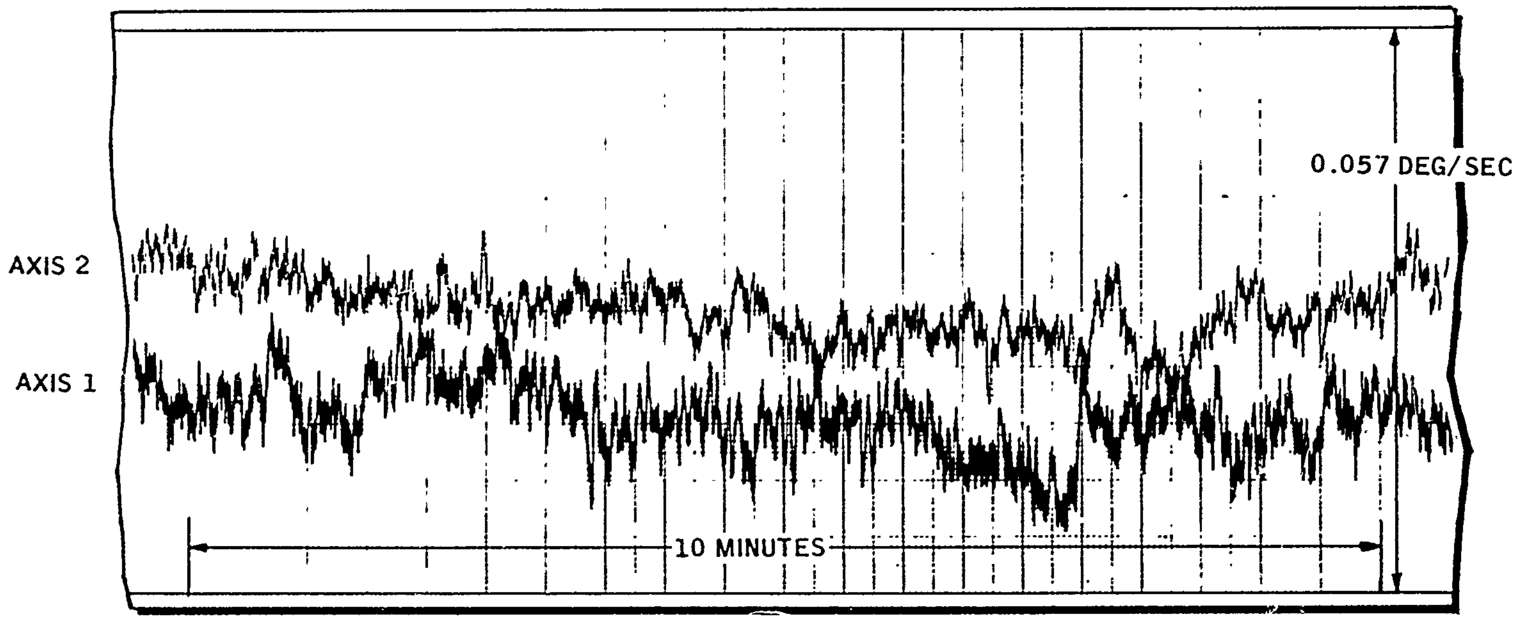


Figure 11. Short Term (10 Minutes) Zero Rate Error Stability

LINEARITY AND CROSS COUPLING

Honeywell defines linearity for the GG2500LC MHD Rate Sensor as the maximum deviation from a least-squares best-fit straight line expressed as a percentage of the full-scale input. In a like manner, cross coupling is defined as the maximum deviation from a least-squares best-fit straight line based on all output data points for input about the opposite axis and expressed as a percentage of the full-scale input of the opposite axis.

Since Honeywell specifies the full-scale range of the GG2500 MHD Rate Sensor at ±480 deg/sec, this gives rise to the question of what is the performance capability for lesser full-scale ranges.

Linearity and cross coupling data is presented here for one GG2500 Rate Sensor (S/N S-8) for input ranges of 0 to ±20 deg/sec, 0 to ±60 deg/sec, and 0 to ±480 deg/sec. In each case, the calculations were based on a least-squares best-fit straight line for that range. The data can be summarized as follows:

Full-Scale Range	Linearity % Full-Scale (Spec = 0. 1%)	Cross Coupling % Full-Scale (Spec = 0. 5%)
± 20 deg/sec	0. 086	0. 058
± 60 deg/sec	0. 096	0. 092
±480 deg/sec	0. 070	0. 223

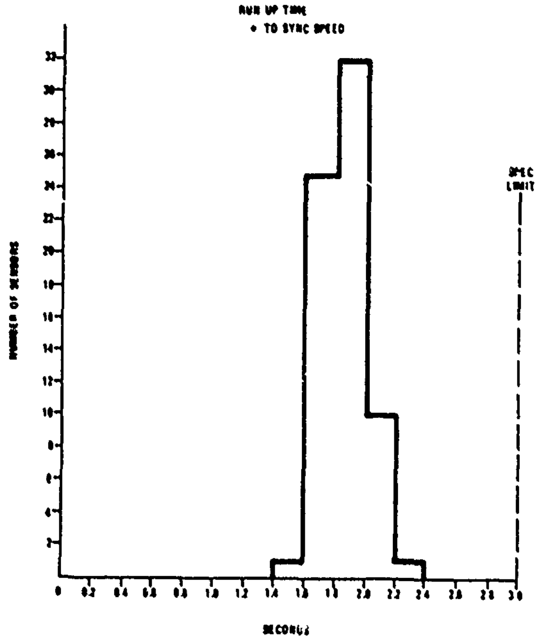
ANGULAR ACCELERATION SENSITIVITY

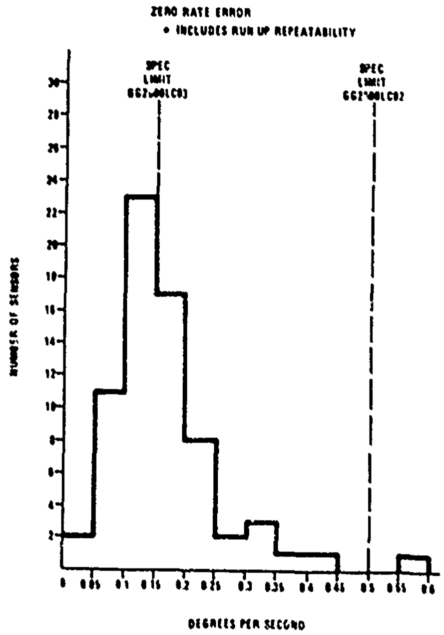
Since the basic transducer of the GG2500 is an angular accelerometer, a question that frequently arises is that of the sensitivity of the GG2500 to angular accelerations. As a matter of fact the GG2500 is virtually insensitive to angular accelerations. This is because the I/C time constant of the mercury torus is so great that at the frequencies of interest the transducer is basically an angular rate sensor.

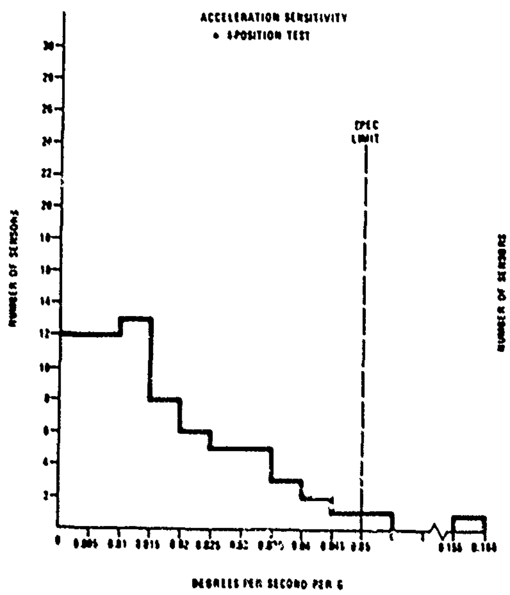
As proof, consider the frequency response curves of Figure 10. Since these curves are run using an oscillating table the MHD was subjected to angular accelerations during these tests. It will be noted that the amplitude response curves are flat out to frequencies approaching the rotor speed. If the MHD were sensitive to these angular accelerations then the response curves should exhibit a 6 db per octave rise. Such was not the case. Honeywell has also run angular acceleration tests about the spin axis. Again no measurable effect was observed.

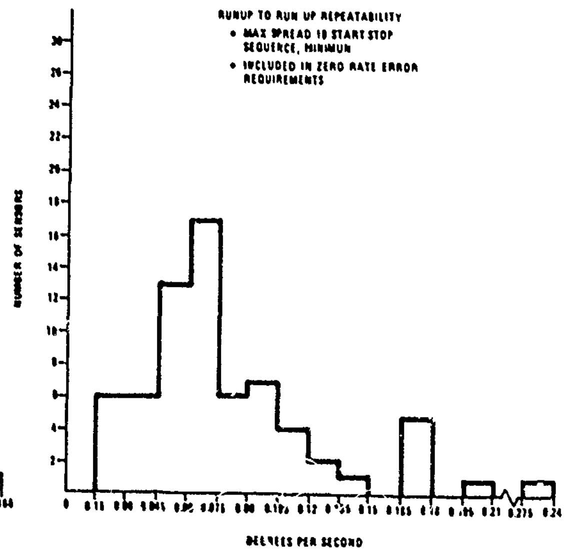
PERFORMANCE HISTOGRAMS

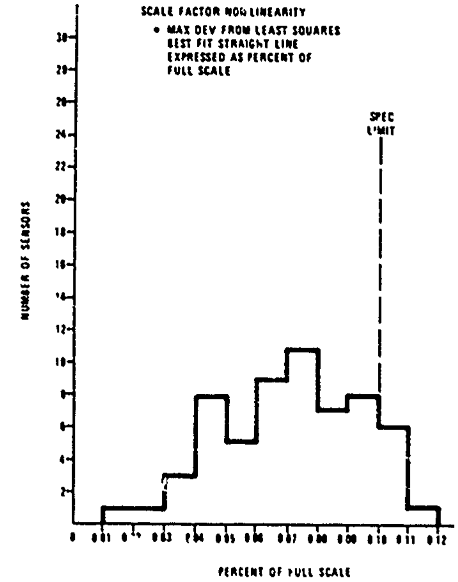
Histograms of critical performance parameters from the most recent 68 production units are shown below. Histograms of threshold and hysteresis are not plotted since they are within 0.01 deg/sec sensitivity of the device.

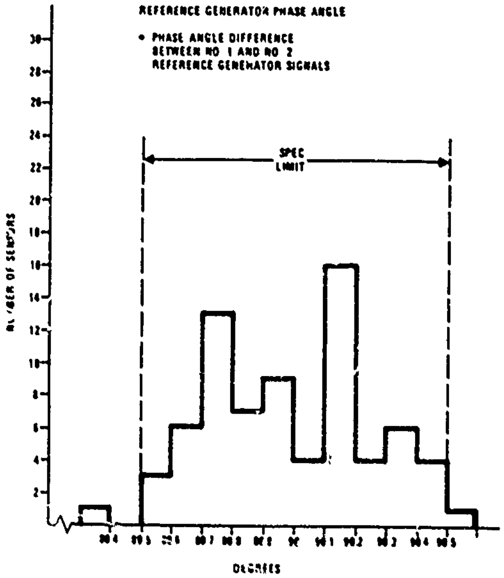


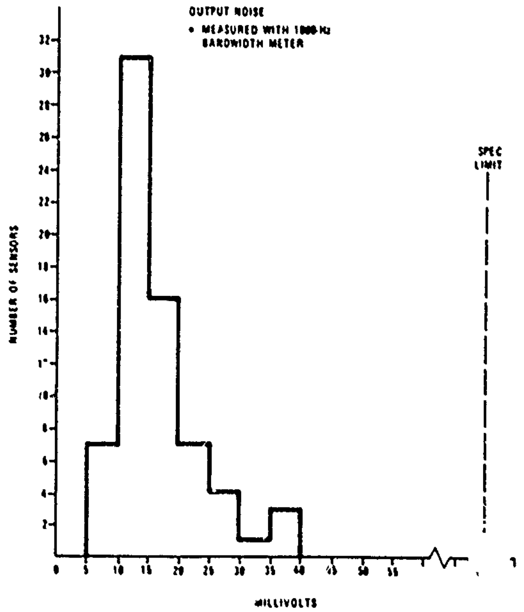


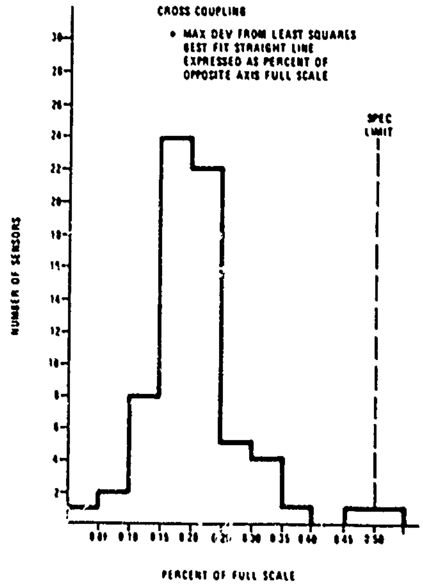




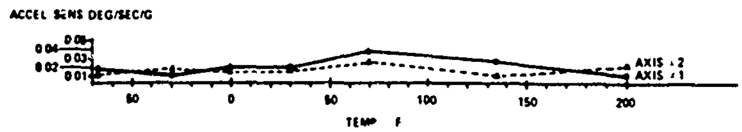

SCALE FACTOR NON LINEARITY
• MAX DEV FROM LEAST SQUARES BEST FIT STRAIGHT LINE EXPRESSED AS PERCENT OF FULL SCALE
SPEC LIMIT
NUMBER OF SENSORS
PERCENT OF FULL SCALE


REFERENCE GENERATOR PHASE ANGLE
• PHASE ANGLE DIFFERENCE BETWEEN NO 1 AND NO 2 REFERENCE GENERATOR SIGNALS
SPEC LIMIT
DEGREES

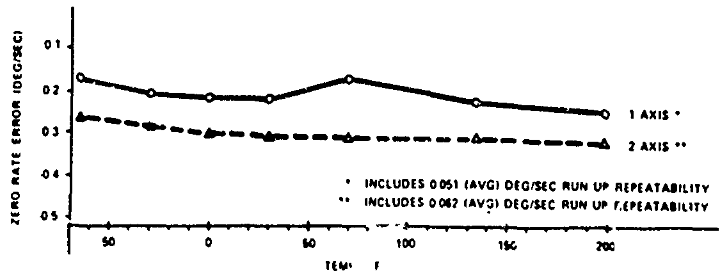

OUTPUT NOISE
• MEASURED WITH 1000-Hz BANDWIDTH METER
SPEC LIMIT
NUMBER OF SENSORS
MILLIVOLTS


CROSS COUPLING
• MAX DEV FROM LEAST SQUARES BEST FIT STRAIGHT LINE EXPRESSED AS PERCENT OF OPPOSITE AXIS FULL SCALE
SPEC LIMIT
NUMBER OF SENSORS
PERCENT OF FULL SCALE

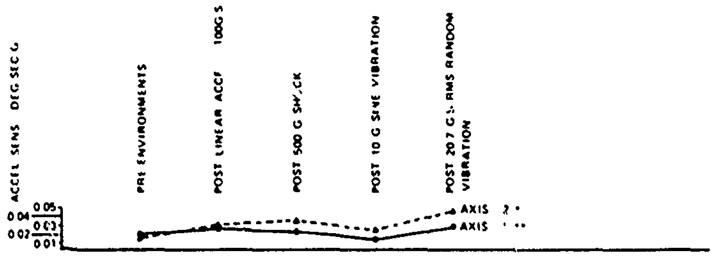
QUALIFICATION TEST PERFORMANCE DATA



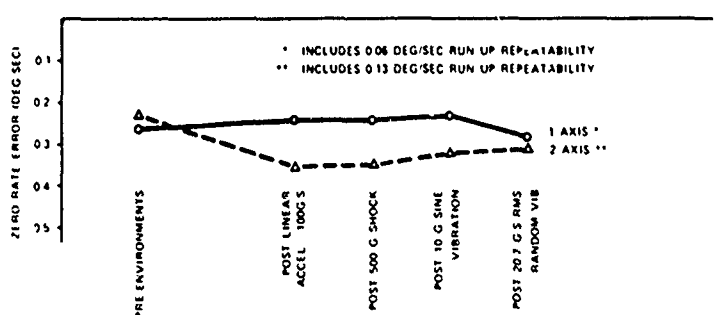
Acceleration Sensitivity Versus Temperature



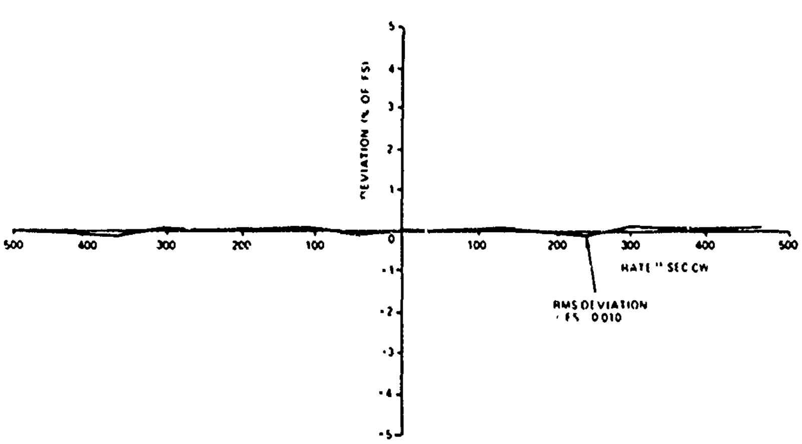
Zero Rate Error Versus Temperature



Acceleration Sensitivity Versus Environments



Zero Rate Error Versus Environments



Linearity Deviation

Detailed data is available for discussion on any GG2500 parameter.

APPENDIX B
TORQUE MOTOR AND SERVO AMPLIFIER SPECIFICATIONS

CLIFTON PRECISION
LITTON SYSTEMS, INC.

ACCEPTANCE TEST DATA SHEET

UNIT TYPE: DPH-3320-A-2T
FUNCTION: TORQUE MOTOR POTENTIOMETER ASSEMBLY

PARAMETER	UNITS	VALUE
Rated Voltage	Volts	29.5
Terminal Resistance	Ohms	3.06
Stall Current (I_S)	Amps	9.65
No Load Speed	Rad/Sec	159
Torque Sensitivity	Oz-In/Amp	24.9
Peak Torque @ I_S	Oz-In	240
Back E.M.F.	V/Rad/Sec	178
Inductance	Millihenries	1.4
Friction Torque	Oz-In	5
Armature Inertia	Oz-In-Sec^2	.016
Acceleration	Rad/Sec^2	15,000
Pot Resistance	Ohms	5014
Linearity	Percent	.22

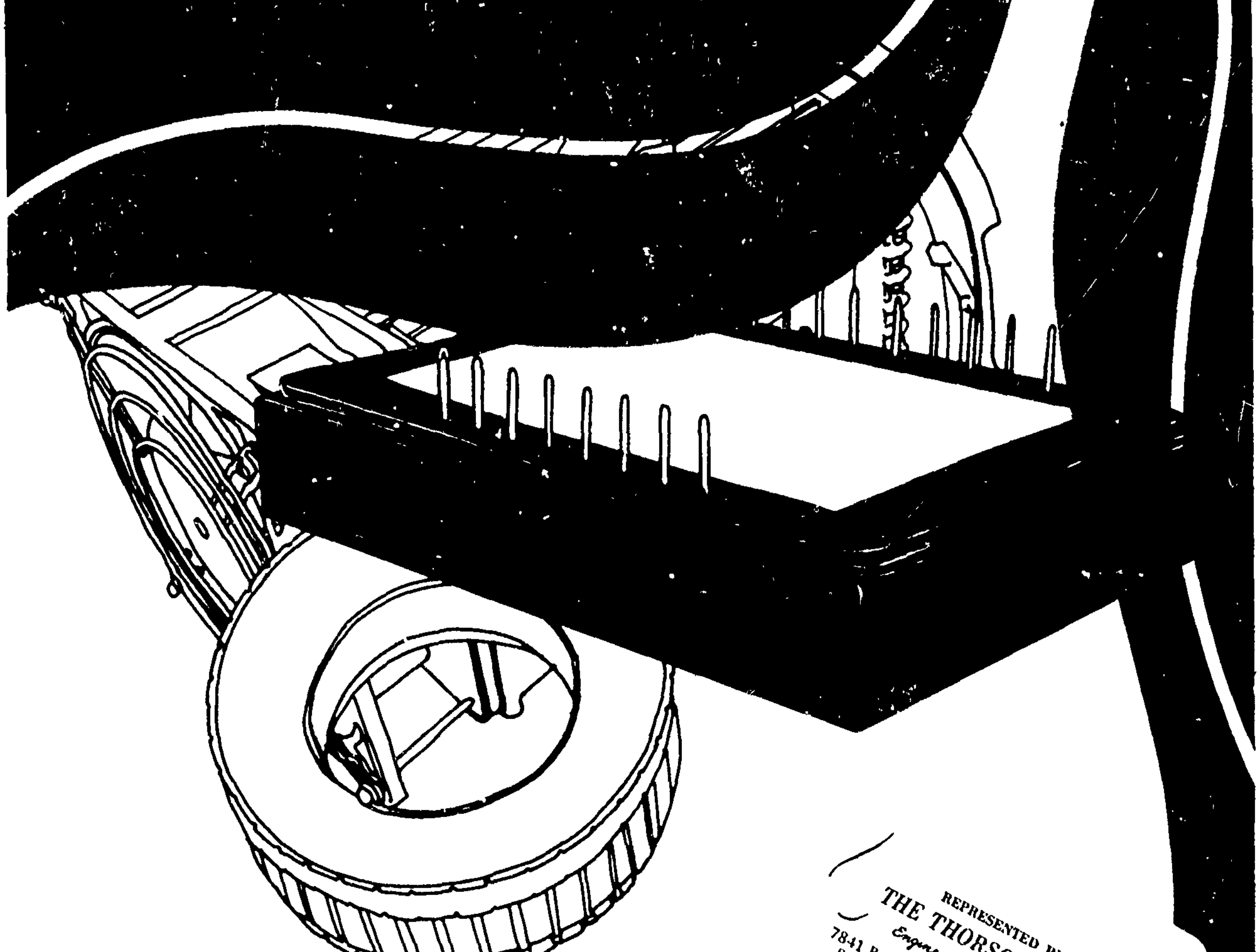
UNIT TYPE: DPH-1990-B-2T
FUNCTION: TORQUE MOTOR POTENTIOMETER ASSEMBLY

PARAMETER	UNITS	VALUE
Rated Voltage	Volts	28
Terminal Resistance	Ohms	9.301
Stall Current (I_S)	Amps	3.11
No Load Speed	Rad/Sec	199.91
Torque Sensitivity	Oz-In/Amp	18.837
Peak Torque @ I_S	Oz-In	56.64
Back E.M.F.	V/Rad/Sec	.135
Inductance	Millihenries	3.21
Friction Torque	Oz-In	1.28
Armature Inertia	Oz-In-Sec^2	.0015
Acceleration	Rad/Sec^2	37,760
Pot Resistance	Ohms	5171
Linearity	Percent	<.25

EM-1800 Series

D.C. SERVO AMPLIFIERS

25W-1500W 28-48-60 volts



REPRESENTED BY
THE THORSON COMPANY
Engineering Representatives
7841 BALBOA AVENUE, SUITE 108
SAN DIEGO, CALIFORNIA 92111
(714) 292-8525

TTL logic-level inhibit

Specialty Products Di

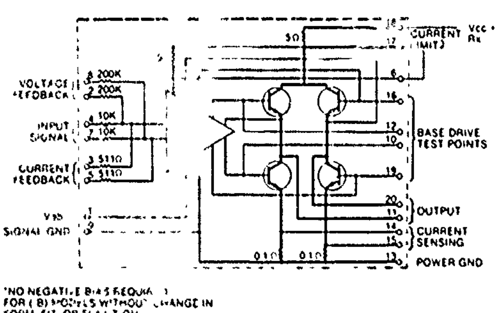
EM 1800 Series D.C. SERVO AMPLIFIERS 25W-1500W 28-48-60 volts

- Single Power Supply (-15V bias supply not required for -B models).
- Aluminum Enclosure used for 25W Amplifier for Improved Heat Transfer.
- Dead Band in Current Amplifier Mode Reduced.
- Three Supply Voltage Families of Amplifiers for better Matching.
- TTL Logic-Level inhibit gate for Computer Controlled Shutdown Applications.

Description

The EM1800 Series Linear DC Servo amplifiers are designed to drive DC torque motors, other DC servo motors and low inertia motors. Versatility of application is made possible by user connections to program for either voltage amplifier or current amplifier operation. Adjustable gain and current limiting can be user programmed with external resistors. A TTL logic-level inhibit gate can also be provided as an option for computer controlled shutdown applications. The requirement for a low-power negative bias supply has been eliminated without changing form, fit, or function of the plug-in modular amplifiers. Special circuitry reduces deadband thereby minimizing crossover distortion. Power output capabilities of the plug-in amplifiers range from 25 to 300 watts. Amplifier assemblies using the plug-in amplifiers as drivers have power output capabilities of 400 to 1500 watts.

Connectors on the plug-in amplifiers are in the form of twenty .040 inch diameter gold-plated pins that protrude from the encapsulated module. Ease of application is made possible with the use of a mating socket (SO-1801) that fits all of the plug-in series amplifiers. The 25 watt amplifiers are encapsulated inside a black anodized aluminum shield. The 200 and 300 watt amplifiers have a surface ground aluminum platen on which is attached four NPN power transistors. This power bridge is driven by the basic 25 watt amplifier (see Figure 1) and the entire circuit is encapsulated in a thermally-conductive epoxy.



BLOCK DIAGRAM FOR EM1802 EM1803 & EM1818

FIGURE 1

Power dissipation capability of the amplifiers can be increased with the use of external heatsinks and/or forced air cooling. Most applications require the use of an external heatsink. The 200 and 300 watt amplifiers have a surface ground platen with four thru-holes to provide heatsink attachment. A heatsink (HS-1801) is available made from a black anodized aluminum extrusion, with four drilled and tapped holes, and having a thermal resistance of approximately 1.2°C/W to fit the 200 and 300 watt amplifiers.

Higher power outputs can also be obtained by using the 25 watt amplifier module as a driver for an external H-type power bridge consisting of NPN silicon power transistors (see Figure 2). Amplifier assemblies using this technique are available for power outputs of 400 to 1500 watts complete with plug-in driver amplifier, socket, power transistors mounted to integral heatsink, and forced air cooling where needed.

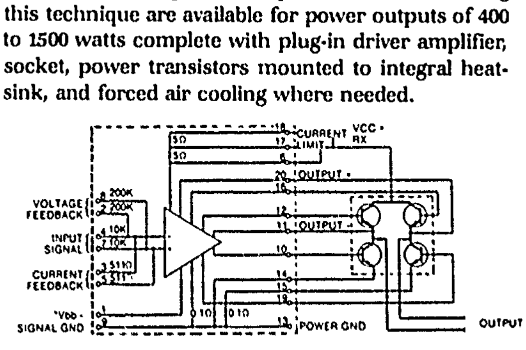


FIGURE 2

BLOCK DIAGRAM FOR EM1801 EM1806 & EM1817 WITH EXTERNAL BRIDGE

Operation

General

The input signal is applied to pins 4 and 7. Pin 7 is the offset adjust and is usually connected directly to pin 9 or through offset circuitry depending on whether the amplifier is connected for voltage or current operation. (See discussion under "Offset Adjustment"). Close-tolerance 10KΩ input resistors make up part of the total summing junction to a high gain differential amplifier. This input pre-amplifier generates differential output signals which drive an H-type power bridge. Special circuitry assures equal power dissipation in the bridge transistors under normal operating conditions where current output is below the set limit value. The bridge construction allows the use of a single-polarity high-voltage source and enables the output pins, 11 and 20, to switch polarity while the load floats above ground potential.

Single Power Supply

The -B designation identifies the amplifier model that does not require a -15V bias supply. The -A model should be selected for those applications where 15V bias supply is readily available. Both models have the same physical dimensions and are pin-for-pin interchangeable (Pin 1 has no-connection on the -B models).

Supply Voltage Selection

Three amplifier families are available for operation with supply voltages of +28 Volt, +48 Volt, and +60 Volt. This expanded choice of supply voltages allows for better matching to minimize internal dissipation in the amplifier. MIL-STD-704 is applicable to the +28 Volt amplifiers.

Current Limit

An internal current-limit circuit senses and clamps the output current at 0.2 amperes. The value of the current-limit (I_{CL}) is adjustable to obtain higher currents by the use of an external current-limit resistor (R_x) which is connected between pins 17 and 18 with pin 17 jumpered to pin 6. The value of R_x is calculated by the formula:

$$R_x = \frac{2}{I_{CL} - 0.4} \qquad \text{Eq. 1}$$

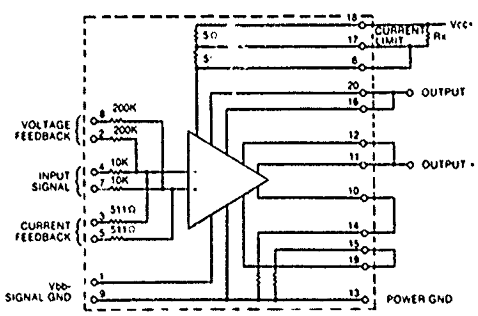
NOTE: The dissipation rating of R_x must be considered:

$$PD_{Rx} = (I_{CL})^2 R_x \qquad \text{(Double for safety margin)} \qquad \text{Eq. 2}$$

Voltage Or Current Amplifier Operation

Voltage Amplifier

Programming for a voltage or a current amplifier becomes a simple matter of connecting the proper feedback to the input summing junctions. Whenever the 25 watt amplifier is used as a motor driver, it should be connected as shown in Figure 3 before the



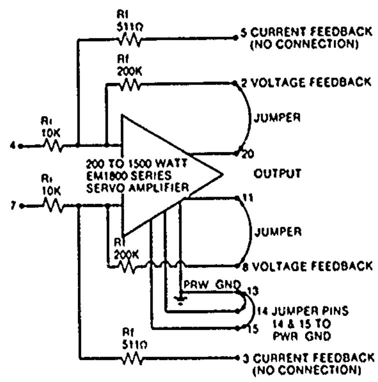
*NO NEGATIVE BIAS REQUIRED FOR (B) MODELS WITHOUT CHANGE IN FORM FIT OR FUNCTION

FIGURE 3 BLOCK DIAGRAM FOR EM1801 EM1806 & EM1817

feedback connections are applied. Otherwise, to achieve the voltage amplifier mode, jumper pin 20 to pin 2 and pin 11 to pin 8. In the voltage amplifier mode, pin 14 and pin 15 should be connected to power ground (pin 13) to avoid unnecessary power dissipation in the current sense resistors (see Figure 4). The voltage gain is factory set for 20V/V. Standard operational amplifier techniques can be used to change the gain within reasonable limits.

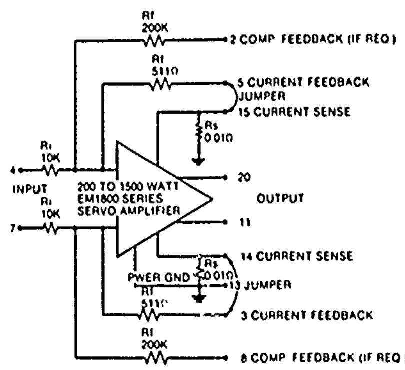
Current Amplifier

For the current amplifier mode, jumper pin 3 to pin 14 and pin 5 to pin 15 (see Figure 5). The current gain is factory set for the plug-in amplifiers at 0.5A/V. Standard operational amplifier feedback techniques can be used to change the gain within reasonable limits.



VOLTAGE AMPLIFIER CONFIGURATION

FIGURE 4

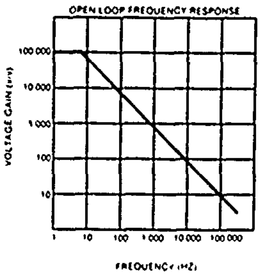


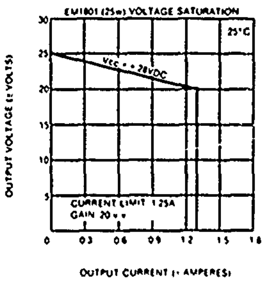
CURRENT AMPLIFIER CONFIGURATION

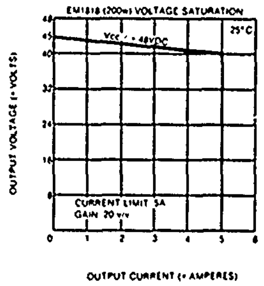
FIGURE 5

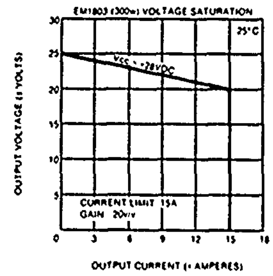
Operation in the current feedback mode with a reactive load can cause a phase shift between the output voltage and current. Because the feedback is a current related signal obtained across current sense resistors, the feedback will be phase shifted with respect to the input voltage. If enough shift occurs, the circuit may oscillate and compensation will be necessary. A series resistor-capacitor network connected in the voltage feedback circuit is one approach to compensation.

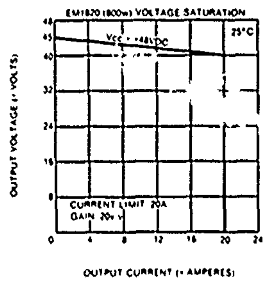
EM-1800 Series D.C. SERVO AMPLIFIERS 25W-1500W 28-48-60 volts

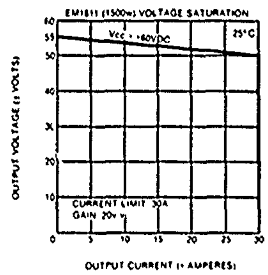


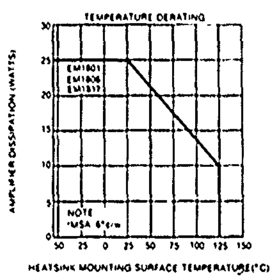


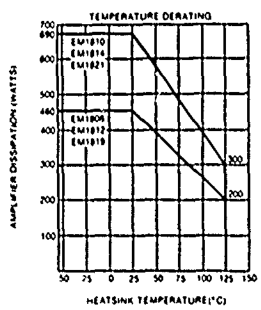


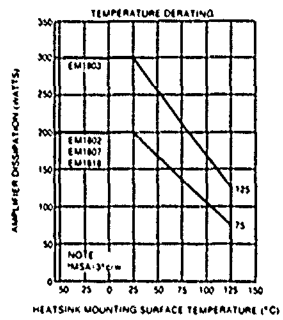


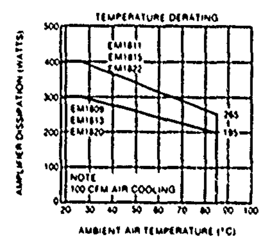


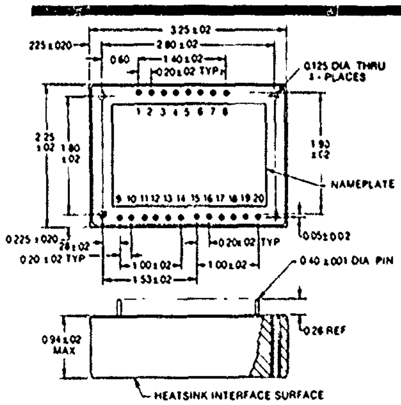




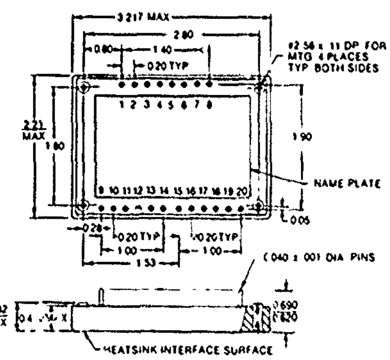




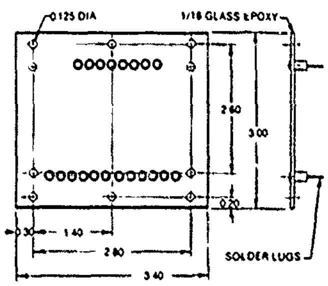




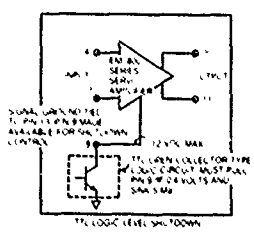
OUTLINE & DIMENSION FOR EM1802 EM1803 EM1807 & EM1818



OUTLINE & DIMENSIONS FOR EM18.. EM1806 & EM1817



OUTLINE & DIMENSION FOR SO1801



Specialty Products Division INLAND MOTOR

APPENDIX C
TORQUE MOTOR MODEL DERIVATION FOR CURRENT AND VOLTAGE DRIVE

CURRENT DRIVE

The amplifier/motor control configuration for the current drive system is shown in figure C-1.

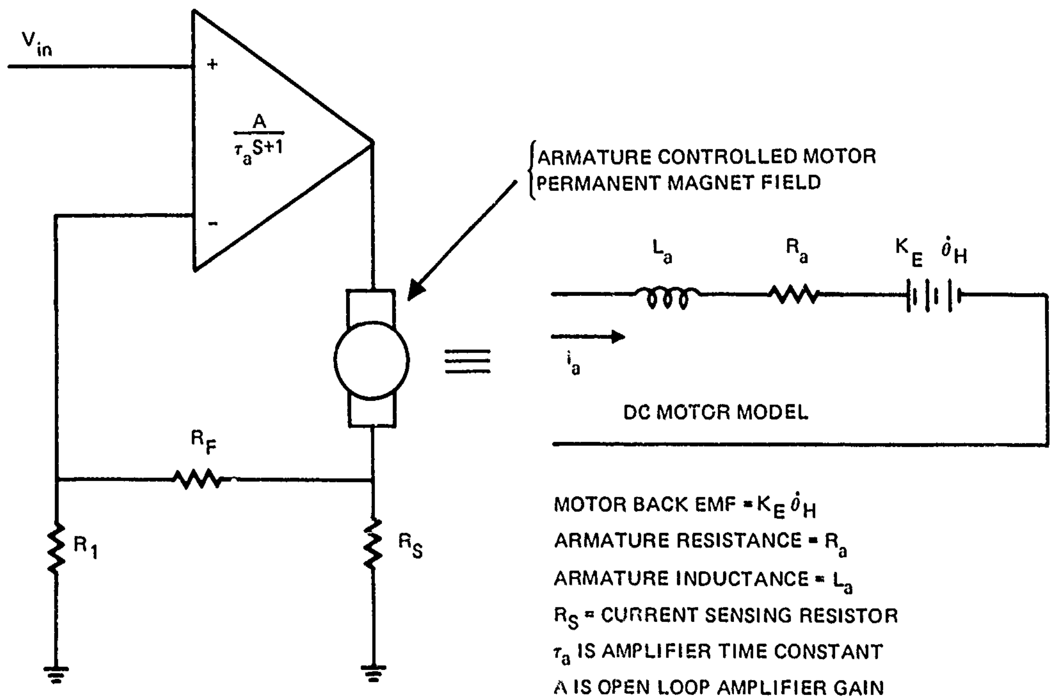


Figure C-1. Current drive amplifier/servo motor.

Figure C-2, the amplifier/motor configuration, shows the motor model incorporated into the diagram.

$$\text{Let } A' = \frac{A}{\tau_a S + 1}$$

then

$$V_2 = \frac{E_S R_F}{R_1 + R_F} = E_s b$$

where

$$b = \frac{R_F}{R_1 + R_F}$$

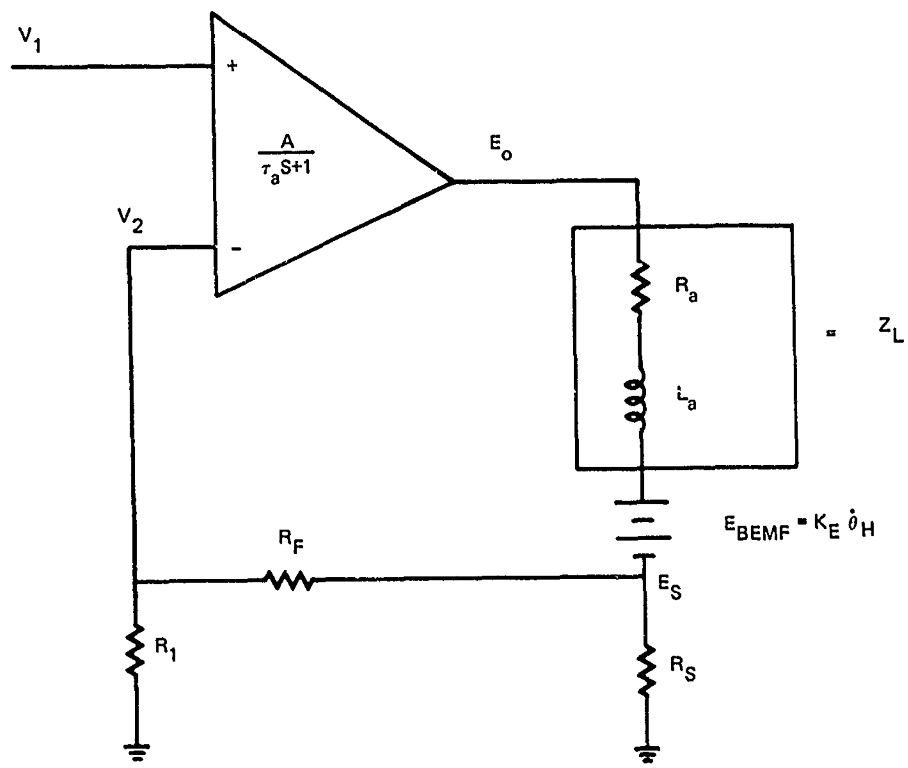


Figure C-2. Amplifier/motor diagram.

$E_o = (V_1 - V_2)\, A'$

$$\therefore\ V_2 = -\left(\frac{E_o}{A'} - V_1\right) \qquad (1)$$

$I_L = \dfrac{E_o - E_{BEMF}}{Z_L}$ assuming E_s is small

$E_s = I_L R_s$

$$\therefore\ V_2 = \frac{(E_o - E_{BEMF})\, b R_s}{Z_L} \qquad (2)$$

Combining (1) and (2) and solving for E_o

$$-\frac{E_o}{A'} + V_1 = \left(\frac{E_o - E_{BEMF}}{Z_L}\right) b R_s$$

$$V_1 = \frac{E_o\, b\, R_s}{Z_L} - \frac{E_{BEMF}\, b\, R_s}{Z_L} + \frac{E_o}{A'}$$

$$V_1 = E_o \left(\frac{A\, R_s\, b + Z_L}{A'\, Z_L} \right) - \frac{E_{BEMF}\, R_s\, b}{Z_L}$$

$$\boxed{E_o = \frac{V_1 + \dfrac{E_{BEMF}\, R_s\, b}{Z_L}}{\dfrac{A'\, R_s\, b + Z_L}{A\, Z_L}}} \tag{3}$$

Also

$$E_o = I_L\, Z_L + E_{BEMF} \tag{4}$$

Now combine (3) and (4) and solve for I_L

$$I_L\, Z_L + E_{BEMF} = \frac{V_1 + \dfrac{E_{BEMF}\, R_s\, b}{Z_L}}{\dfrac{A'\, R_s\, b + Z_L}{A'\, Z_L}}$$

$$I_L\, Z_L = \frac{A'\, Z_L\, V_1 + E_{BEMF}\, A\, R_s\, b}{A'\, R_s\, b + Z_L} - E_{BEMF}$$

$$I_L\, Z_L = \frac{A'\, Z_L\, V_1 + E_{BEMF}\, A\, R_s\, b - E_{BEMF}\, A\, R_s\, b - E_{BEMF}\, Z_L}{A'\, R_s\, b + Z_L}$$

$$I_L\, Z_L = \frac{A'\, Z_L\, V_1 - E_{BEMF}\, Z_L}{A'\, R_s\, b + Z_L}$$

$$\boxed{I_L = \frac{A'\, V_1 - E_{BEMF}}{A'\, R_s\, b + Z_L}} \tag{5}$$

Now, replacing I_L by I_M

Z_L by $S\, L_a + R_a$

and

E_{BEMF} by $K_E\, N\, \dot{\theta}_H$

$$I_M = \frac{A'\, V_{in} - K_E\, N\, \dot{\theta}_H}{A'\, R_s\, b + S L_a + R_a} \tag{6}$$

The load torque, T_L, is given by $J_T\, S^2\, \theta_H + DS\, \theta_A$ (7)

where

$J_T = N^2 J_M + J_L$ is the total inertia and

N is the gear ratio

J_M is the motor inertia

J_L is the load inertia

D is the viscous damping

The desired torque is given by:

$$T_d = N K_T I_M \text{ where } K_T \text{ is the torque sensitivity constant} \tag{8}$$

Now we can equate the load torque (7) with the desired torque (8) to obtain an expression for the amplifier/motor/load transfer function $\dot{\theta}_H/V_{in}$.

$$N K_T I_M = J_T S^2 \theta_H + DS \theta_H$$

$$N K_T I_M = \dot{\theta}_H (J_T S + D)$$

Now substitute expression (6) for I_M

$$N K_T \left[\frac{A' V_{in} - K_E N \dot{\theta}_H}{A' R_s b + S L_a + R_a}\right] = \dot{\theta}_H (J_T S + D)$$

$$N K_T A' V_{in} - N^2 K_E K_T \dot{\theta}_H = \dot{\theta}_H (J_T S + D)(A' R_s b + S_{La} + R_a)$$

$$N K_T A' V_{in} = \dot{\theta}_H \Big[N^2 K_E K_T + J_T S A R_s b + S^2 J_T L_a + S J_T R_a + D A' R_s b$$
$$+ S D L_a + D R_a\Big]$$

$$\boxed{\frac{\dot{\theta}_H}{V_{in}} = \frac{N K_T A'}{J_T L_a S^2 + (J_T A' R_s b + J_T R_a + D L_a) S + N^2 K_E K_T + D A' R_s b + D R_a}}$$

or in another form

$$\boxed{\frac{\dot{\theta}_H}{V_{in}} = \frac{N K_T A'}{(L_a S + R_a)(J_T S + D) + A' R_s b (J_T S + D) + N^2 K_E K_T}} \tag{10}$$

Amplifier/Motor/Load Transfer Function

Substituting $\dfrac{A}{\tau_a S + 1}$ for A'

we get

$$\frac{\dot{\theta}_H}{V_{in}} = \frac{N K_T A}{(\tau_a S + 1)(L_a S + R_a)(J_T S + D) + A R_s b (J_T S + D) + N^2 K_E K_T (\tau_a S + 1)} \tag{11}$$

Thus the amplifier/motor/load block diagram is as follows:

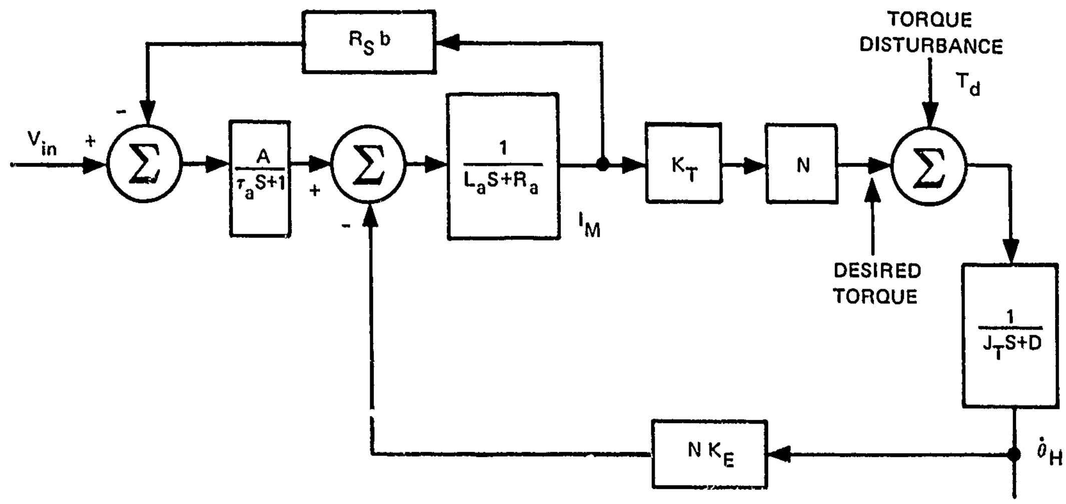


Figure C-3. Amplifier/motor/load block diagram for current drive servo control.

VOLTAGE DRIVE

The model for the DC armature controlled motor is shown in figure C-4.

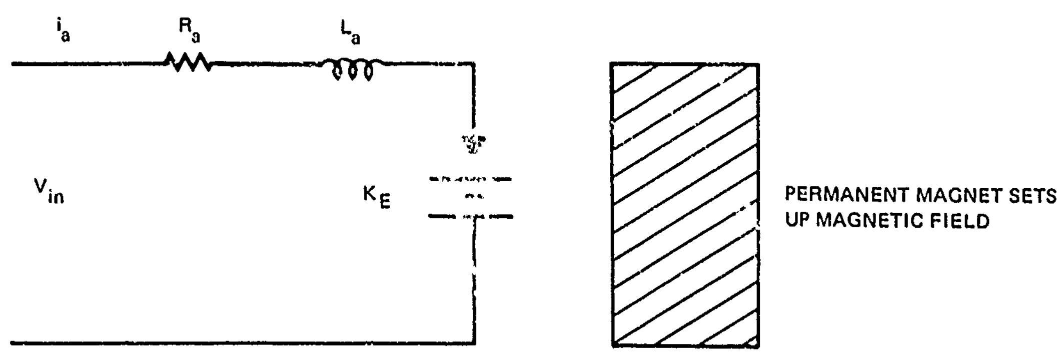


Figure C-4. DC armature controlled motor.

The voltage equation for the motor is

$$V = ia\, R_a + \frac{dia}{dt} L_a + K_E \dot{\theta}_M \tag{12}$$

Taking the LaPlace transform of each side of (12) we get

$$V(s) = I_a(s) R_a + S I_a(s) L_a + SK_E \theta_m(s) \tag{13}$$

The motor torque is

$$T_M = N K_T I_a \tag{14}$$

and the load torque is

$$T_L = J_T S^2 \theta_H(s) + D S \theta_H(s) \tag{15}$$

where

J_t is the total inertia

$$J_t = N^2 J_m + J_L \tag{16}$$

and

D is the total viscous damping

$$D = N^2 D_m + D_L \tag{17}$$

and

θ_H is the output shaft angle of the gear train (gimbal displacement)

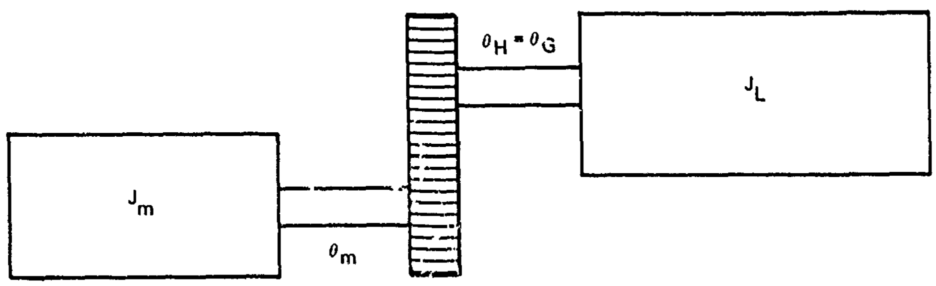


Figure C-5. Motor/load gear ratio diagram.

Substituting 14 into 13

$$V(s) = \frac{T_M R_a}{N K_T} + \frac{S T_M L_a}{N K_T} + S K_E N \theta_H \tag{18}$$

and equating motor torque to load torque (18) becomes

$$V(s) = \frac{S\,\theta_H}{N}\left[\left(\frac{J_T\,S + D}{K_T}\right) R_a + \left(\frac{J_T\,S^2 + DS}{K_T}\right) L_a + N^2\,K_E\right] \tag{19}$$

from which the motor load transfer function is derived

$$\frac{\theta_H(s)}{V(s)} = \frac{N\,K_T}{S\left[J_t\,L_a\,S^2 + (J_t\,R_a + D\,L_a)\,S + D\,R_a + N^2\,K_t\,K_E\right]} \tag{20}$$

or

$$\boxed{\frac{\dot{\theta}_H}{V} = \frac{N\,K_T}{J_t\,L_a\,S^2 + (J_t\,R_a + D\,L_a)\,S + D\,R_a + N^2\,K_t\,K_E}} \tag{21}$$

The block diagram for the voltage drive servo control is shown in figure C-6.

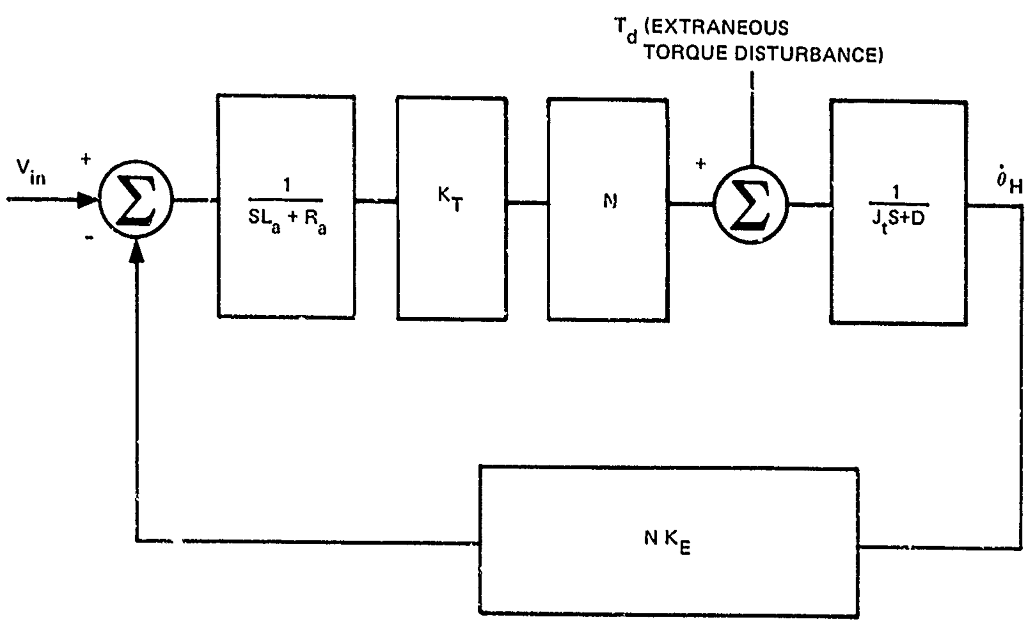


Figure C-6. Voltage drive servo control block diagram.

APPENDIX D
LOAD INERTIA DERIVATION

This appendix deals with the mathematical derivation of the load inertia for both inner and outer gimbals. Figure D-1 shows the components that comprise the total load inertia. All of the components, excluding the hat, are exact calculations of inertia. The moment of inertia of the hat was an approximation due to its complex geometric shape. Ref 14 was used in the derivation of the following load inertias.

I. OUTER GIMBAL

The moment of inertia for the moving parts of the outer gimbal will be found by calculating the moments for each of the nine parts in figure 1, and adding them. The outer gimbal pivots about a line through the center of mass of the plate or through the axis of the bail ring. All moments will be referred to this line and then summed. The method of calculation for the moment of each part (I_z) will be to calculate the moment (I_{CM}) about the line through the center of mass of the part and parallel to the axis of rotation, then substitute this into the formula

$$I_z = I_{CM} + md^2, \tag{1}$$

12. Baumeister, Theodore, Editor, Mechanical Engineer's Handbook, McGraw-Hill Book Company, 1967.

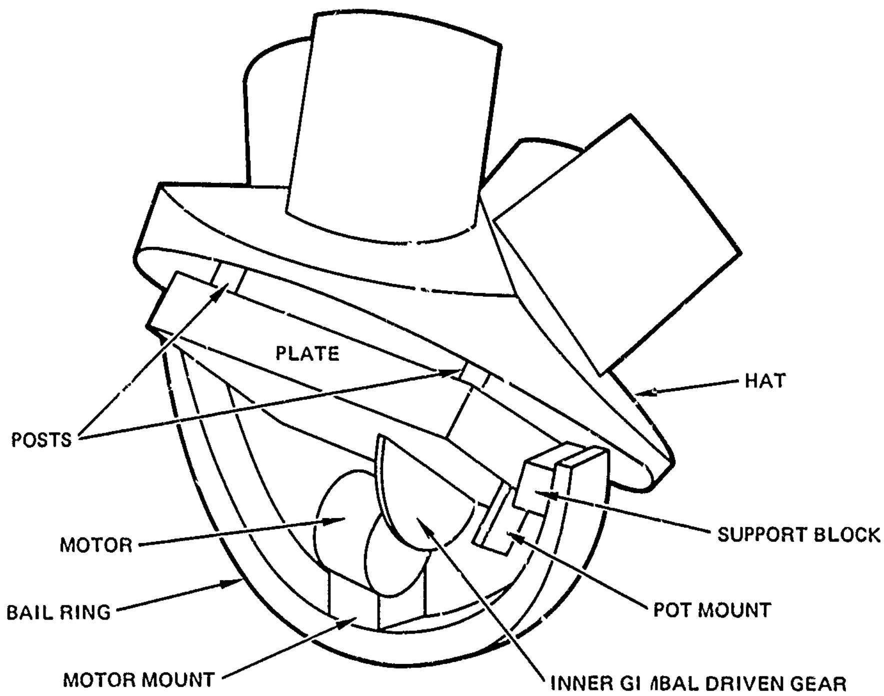


Figure D-1. LADSS platform moment of inertia.

where m is the mass of the part and d is the perpendicular distance from the center of mass of the part to the axis of rotation. Formulas for volumes, centroids and moments of inertia were found in CRC Standard Mathematical Tables 17th Edition. All parts are made of aluminum (density = 2700 Kg/m^3) except the inner gimbal driven gear which is brass (density = 8700 Kg/m^3). Note: all outer gimbal moments will be calculated for the zero position of the inner gimbal. The moment of inertia for the hat will not be calculated directly due to its complexity.

A. Plate

The center of mass of the plate lies on the axis of rotation, thus the following formula applies. $I_Z = m/12\,(a^2 + b^2)$. The dimensions of the plate are .1524 m X .1524 m X .0254 m.

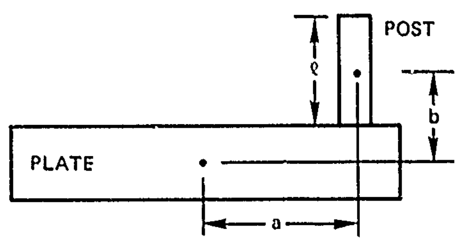
$$m = \rho V = (2700\ Kg/m^3)\,(.1524\ m)^2\,(.0254\ m) = \underline{1.592823\ Kg}$$

$$I_Z = \frac{1.592823\ Kg}{12}\left[(.1524\ m)^2 + (.0254\ m)^2\right]$$

$$\boxed{I_Z = 3.16851 \times 10^{-3}\ Kg\text{-}m^2}$$

B. Posts

There are four cylindrical posts that hold the hat in place on the plate. The position of the posts is symmetric about the axis of rotation, therefore the total moment of inertia for all posts is four times the moment for one post.



Dimensions $\ell = .04572$ m

$r = .00635$ m

$a = .0635$ m

$b = .03556$ m

The moment of inertia about the center of mass (I_{CM}) is given by

$$m\left(\frac{r^2}{4} + \frac{\ell^2}{12}\right).$$

$$m = \rho V = \rho\pi r^2 \ell = (2700\ Kg/m^3)\,(\pi)\,(.00635\ m)^2\,(.04572\ m)$$

$\underline{m = .015637 \text{ Kg}}$ Total mass for 4 posts = $\underline{.062548 \text{ Kg}}$

Then

$$I_{CM} = (.015637 \text{ Kg}) \left[\frac{(.00635 \text{ m})^2}{4} + \frac{(.04572 \text{ m})^2}{12}\right]$$

$$I_{CM} = 2.88158 \times 10^{-6} \text{ Kg-m}^2.$$

I_z for one post is given by $I_z = I_{CM} + md^2$, where $d = \sqrt{a^2 + b^2}$. Thus

$$I_z = (2.88158 \times 10^{-6} \text{ Kg-m}^2) + (.015637 \text{ Kg}) [(.0655 \text{ m})^2 + (.03556 \text{ m})^2]$$

$$I_{z(\text{for one post})} = 8.57071 \times 10^{-5} \text{ Kg-m}^2.$$

For all four posts

$$\boxed{I_z = 3.42828 \times 10^{-4} \text{ Kg-m}^2}$$

C. Pot Mount

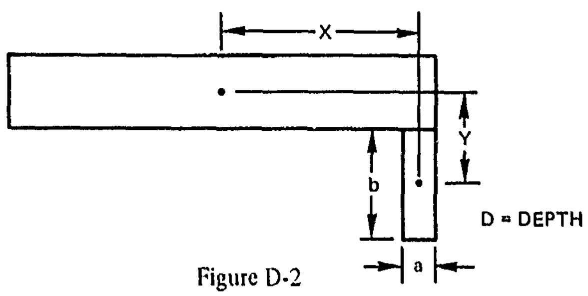


Figure D-2

a = .00508 m
b = .0254 m
x = .07366 m
y = .0254 m
D = .0381 m

The moment of inertia about the center of mass is given by

$$I_{CM} = \frac{m}{12} (a^2 + b^2)$$

$$m = \rho V = \rho abD = (2700 \text{ Kg/m}^3) (.00508 \text{ m}) (.0254 \text{ m}) (.0381 \text{ m})$$

$m = \underline{.0132735 \text{ Kg}}$

$$\therefore I_{CM} = \frac{(.0132735 \text{ Kg})}{12} \left[(.00508 \text{ m})^2 + (.0254 \text{ m})^2\right]$$

$$I_{CM} = 7.42174 \times 10^{-7} \text{ Kg-m}^2$$

Then I_z is given by $I_z = I_{CM} + md^2$ where $d = \sqrt{x^2 + y^2}$

$$I_z = (7.42174 \times 10^{-7} \text{ Kg-m}^2) + (.0132735 \text{ Kg}) [(.07366 \text{ m})^2 + (.0254 \text{ m})^2]$$

$$\boxed{I_z = 8.1325 \times 10^{-5} \text{ Kg-m}^2}$$

D. Support Block

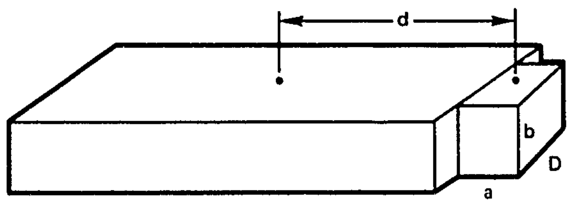


Figure D-3

a = .01778 m

b = .0254 m

D = .0254 m

d = .08382 m

$m = \rho V = \rho abD = (2700 \text{ Kg/m}^3) (.01778 \text{ m}) (.0254 \text{ m})^2$

$\underline{m = 3.09716 \times 10^{-2} \text{ Kg}}$

$$I_{CM} = \frac{m}{12}(a^2 + b^2) = \frac{3.09716 \times 10^{-2} \text{ Kg}}{12}\left[(.01778 \text{ m})^2 + (.0254 \text{ m})^2\right]$$

$$I_{CM} = 2.48105 \times 10^{-6} \text{ Kg-m}^2$$

$$I_z = I_{CM} + md^2 = (2.48105 \times 10^{-6} \text{ Kg-m}^2) + (3.09716 \times 10^{-2} \text{ Kg}) (.08382 \text{ m})^2$$

$$\boxed{I_z = 2.20081 \times 10^{-4} \text{ Kg-m}^2}$$

E. Inner Gimbal Drive Gear

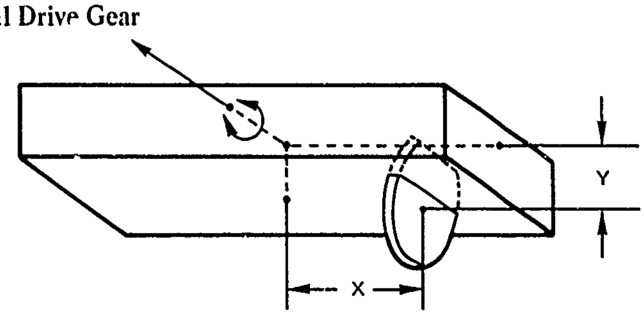


Figure D-4

This gear is half of a circular plate imbedded in the aluminum plate. The moment of inertia will be calculated for the full gear even though the slot was not allowed for in calculating the moment of the plate. The calculation will be as follows.

1. Calculate the mass, $m = \rho V$, using $\rho = 8700\ Kg/m^3$ for brass.
2. Calculate the moment of inertia about the diameter, I_d.
3. Find the location of the center of mass, $\bar{y}$ (perpendicular distance from diameter)
4. Find the moment of inertia about the line parallel to the diameter, through the center of mass, I_{CM}.
5. Calculate I_z using Eq 2.

Dimensions

$r = .04953$ m

$t = .00254$ m (thickness)

$x = .03302$ m

1. $m = \rho V = \rho \cdot \frac{1}{2} \pi r^2 t$

$$m = (8700\ Kg/m^3) \left(\frac{\pi}{2}\right) (.04953\ m)^2\ (.00254\ m)$$

$$\underline{m = .085155\ Kg}$$

2. Moment of inertia about diameter element of mass is given by

$$\rho t\ r\ dr\ d\theta$$

Second moment of element about diameter is given by

$$(\rho t\ r\ dr\ d\theta)\ (r \sin \theta)^2$$

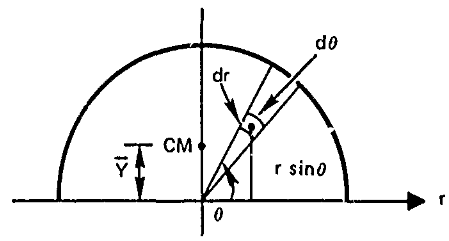


Figure D-5

Thus

$$I_d = \int_{\theta=0}^{\pi} \int_{r=0}^{r} \rho t\ r^3 \sin^2\theta\ dr\ d\theta$$

$$I_d = \rho t \int_{\theta=0}^{\pi} \frac{r^4}{4} \sin^2 \theta\ d\theta$$

$$I_d = \frac{\rho t r^4}{4} \left[\frac{\pi}{2} - \frac{1}{4} \sin 2\pi - \left(0 - \frac{1}{4} \sin 0\right)\right] = \frac{\rho t r^4}{4} \left(\frac{\pi}{2}\right)$$

$$\underline{I_d = \frac{\rho \pi t r^4}{8} = 5.22259 \times 10^{-5}\ Kg\text{-}m^2}$$

3. Distance of center of mass from diameter ($\bar{y}$) element of mass = $\rho t\ r\ dr\ d\theta$

First moment of element about diameter is given by $(\rho t\ r\ dr\ d\theta)\ (r \sin \theta)$

Then

$$M_x = \int_{\theta=0}^{\pi} \int_{r=0}^{r} \rho t\, r^2 \sin\theta \, dr\, d\theta$$

$$M_x = \rho t \int_{\theta=0}^{\pi} \frac{r^3}{3} \sin\theta \, d\theta$$

$$M_x = \frac{\rho t r^3}{3} [-\cos\pi + \cos 0] = \frac{2\rho t r^3}{3}$$

Now,

$$\bar{y} = \frac{M_x}{m} = \frac{\frac{2\rho t r^3}{3}}{\frac{\rho \pi r^2 t}{2}} = \frac{4r}{3\pi}$$

$\underline{\bar{y} = .021021 \text{ m}}$

4. To find the moment of inertia about the center of mass, I_{CM} use Eq. 2 with $I_z = I_d$, $d = \bar{y}$ and solve for I_{CM}.

$$I_d = I_{CM} + m\bar{y}^2 \Rightarrow I_{CM} = I_d - m\bar{y}^2$$

$$I_{CM} = (5.22259 \times 10^{-5} \text{ Kg-m}^2) - (.085155 \text{ Kg})(.021021 \text{ m})^2$$

$$\underline{I_{CM} = 1.45974 \times 10^{-5} \text{ Kg-m}^2}$$

5. Find I_z using Eq. 2 with $d = \sqrt{x^2 + \bar{y}^2}$

$$I_z = I_{CM} + m(x^2 + \bar{y}^2)$$

$$I_z = (1.45974 \times 10^{-5} \text{ Kg-m}^2) + (.085155 \text{ Kg})[(.03302 \text{ m})^2 + (.021021 \text{ m})^2]$$

$$\boxed{I_z = 1.45072 \times 10^{-4} \text{ Kg-m}^2}$$

F. Inner Gimbal Motor

$\underline{m = .2575 \text{ Kg}}$ (measured)

$r = .0254$ m

$\ell = .0381$ m

$d = .05842$ m

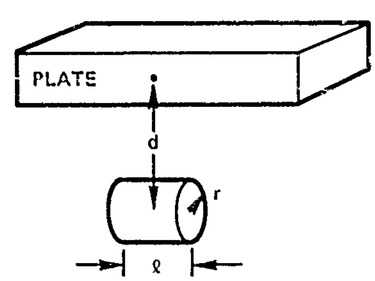


Figure D-6

$$I_{CM} = m\left(\frac{r^2}{4} + \frac{\ell^2}{12}\right) = (.2575\ \text{Kg})\left[\frac{(.0254\ \text{m})^2}{4} + \frac{(.0381\ \text{m})^2}{12}\right]$$

$$I_{CM} = 7.26813 \times 10^{-5}\ \text{Kg-m}^2$$

Then

$$I_z = I_{CM} + md^2 = (7.26813 \times 10^{-5}\ \text{Kg-m}^2) + (.2575\ \text{Kg})\ (.05842\ \text{m})^2$$

$$\boxed{I_z = 9.515 \times 10^{-4}\ \text{Kg-m}^2}$$

G. Motor Mount

a = .02032 m
b = .0381 m
c = .0381 m
d = .085 m

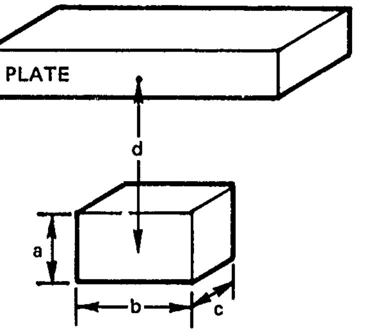


Figure D-7

$$m = \rho V = \rho abc = (2700\ \text{Kg/m}^3)\ (.02032\ \text{m})\ (.0381\ \text{m})\ (.0381\ \text{m})$$

$$\underline{m = .079641\ \text{Kg}}$$

$$I_{CM} = \frac{m}{12}(a^2 + b^2) = \frac{.079641\ \text{Kg}}{12}\left[(.02032\ \text{m})^2 + (.0381\ \text{m})^2\right]$$

$$I_{CM} = 1.23743 \times 10^{-5}\ \text{Kg-m}^2$$

$$I_z = I_{CM} + md^2 = (1.23743 \times 10^{-5}\ \text{Kg-m}^2) + (.079641\ \text{Kg})\ (.085\ \text{m})^2$$

$$\boxed{I_z = 5.87781 \times 10^{-4}\ \text{Kg-m}^2}$$

H. Bail Ring

r_1 = .09525 m
r_2 = .106363 m
h = .03683 m

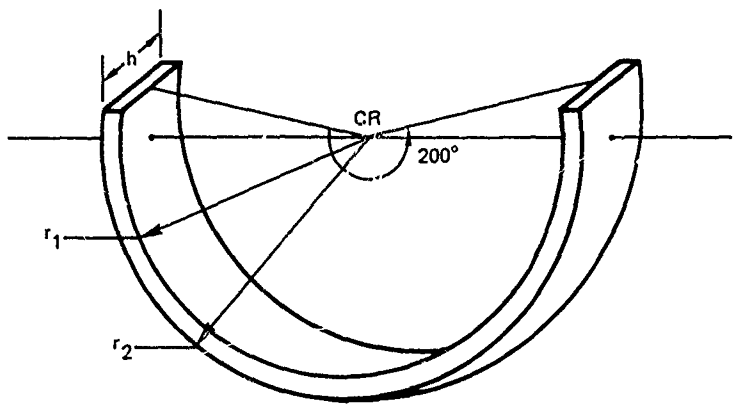


Figure D-8

$$m = \rho V = \rho \frac{200}{360} (\pi r_2^2 h - \pi r_1^2 h) = (\rho \pi h) \left(\frac{200}{360}\right) (r_2^2 - r_1^2)$$

$$m = (2700 \text{ Kg/m}^3) (\pi) (.03683 \text{ m}) \left(\frac{200}{360}\right) [(.106363 \text{ m})^2 + (.09525 \text{ m})^2]$$

$$\underline{m = .388859 \text{ Kg}}$$

$$I_z = \frac{m}{2} (r_2^2 - r_1^2) = \frac{.388859 \text{ Kg}}{2} [(.106363 \text{ m})^2 + (.09525 \text{ m})^2]$$

$$\boxed{I_z = 3.96358 \times 10^{-3} \text{ Kg-m}^2}$$

I. HAT

The moment of inertia of the hat assembly will be approximated by a segment of a spherical shell. The dimensions of the shell were chosen such that, if it were made of aluminum, the mass would coincide with the measured mass, 1.06 Kg. Also the dimensions were chosen so that the center of mass of the shell is located at the estimated center of mass of the hat assembly. A cross section of the shell model is shown in figure D-9, with dimensions.

r_1 = .132801 m
r_2 = .137595 m
h_1 = .09398 m
h_2 = .098774 m
c_1 = .254 m
c_2 = .26401 m
α = 2.558909 rad
s = .038821 m
C_M = center of mass
C_R = center of rotation

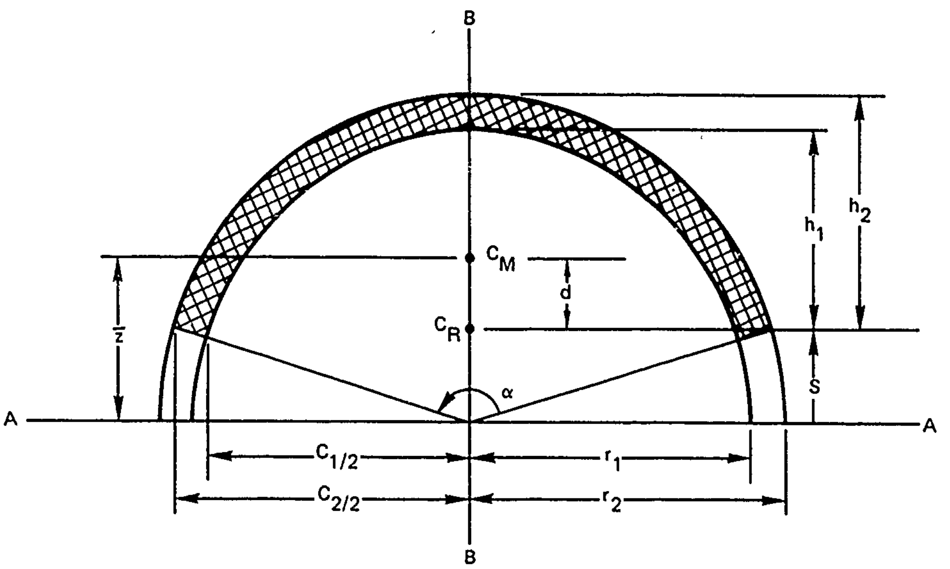


Figure D-9. Model of Hat assembly.

The following formulae were used in calculating some of the dimensions.

$$s = r_1 - h_1$$

$$\alpha = \sin^{-1} \frac{c_1}{2r_1} + \sin^{-1} \frac{c_2}{2r_2}$$

$$c = \sqrt{4h(2r - h)}$$

To find the moment of inertia of the shell, I_s, the following procedure will be used. First an expression for the mass will be found. Then the center of mass will be located using the expression $\bar{z} = M_p/m$ where M_p is the first moment about the plane A–A in figure D-9. Next the moment of inertia about the center of mass, I_{CM}, will be calculated and finally the moment of inertia about the center of rotation, I_{CR}, using Eq. 1.

A. The mass of the shell is given by ρV where $\rho = 2700$ Kg/m^3 (the density of aluminum) and V is the volume. Using spherical coordinates, an element of mass is given by

$$\rho r^2 \sin\phi \, dr d\theta d\phi.$$

Thus the mass is given by

$$m = \rho \int_{\phi=0}^{\alpha/2} \int_{\theta=0}^{2\pi} \int_{r=r_1}^{r_2} r^2 \sin\phi \, dr d\theta d\phi$$

$$\underline{\underline{m = \frac{2\pi}{3} (r_2^3 - r_1^3)(1 - \cos\alpha/2)}}$$

Using the dimensions in figure 9, m = 1.06 Kg.

B. Due to symmetry the center of mass lies on the line B–B in figure D-9. Thus the distance $\bar{z}$ must be calculated. To find $\bar{z}$, the first moment about the polar plane, M_p, must be calculated. Again, an element of mass is given by

$$\rho r^2 \sin\phi \, dr d\theta d\phi$$

and its distance from the polar plane is given by

$$r \cos\phi.$$

Thus

$$M_p = \int_{\phi=0}^{\alpha/2} \int_{\theta=0}^{2\pi} \int_{r=r_1}^{r_2} \rho r^3 \sin\phi \cos\phi \, dr d\theta d\phi$$

$$M_p = \frac{\pi\rho}{4} (r_2^4 - r_1^4) \sin^2\left(\frac{\alpha}{2}\right)$$

Then

$$\bar{z} = \frac{M_p}{m} = \frac{3}{8} \frac{(r_2^4 - r_1^4)}{(r_2^3 - r_1^3)} \left(1 - \cos\frac{\alpha}{2}\right)$$

Substitution yields

$$\bar{z} = .087034 \text{ m}$$

C. The moment of inertia about the line through the center of mass, perpendicular to line B–B, is found by summing the second moments of the mass elements. That is, the mass element times the distance from the line (x) squared. The mass element is as before and the distance squared is given by

$$x^2 = r^2 \sin^2\phi + (r \cos\phi - \bar{z})^2$$

Thus the moment of inertia about the CM line is given by

$$I_{CM} = \int_{\phi=0}^{\alpha/2} \int_{\theta=0}^{2\pi} \int_{r=r_1}^{r_2} \rho r^2 \sin\phi \, [r^2 \sin^2\phi + (r\cos\phi - \bar{z})^2] \, dr d\theta d\phi$$

$$I_{CM} = 3m \left[\frac{1}{5} \left(\frac{r_2^5 - r_1^5}{r_2^3 - r_1^3} \right) - \frac{\bar{z}}{4} \left(\frac{r_2^4 - r_1^4}{r_2^3 - r_1^3} \right) \left(1 + \cos\frac{\alpha}{2}\right) + \frac{\bar{z}^2}{3} \right]$$

$$I_{CM} = 1.13559 \times 10^{-2} \text{ Kg-m}^2$$

D. The total moment of inertia about the axis of rotation can now be found using Eq. 1 with $d = \overline{z} - s$.

$$I_{CR} = I_{CM} + m(\overline{z} - s)^2$$

$$I_{CR} = 1.381986 \times 10^{-2} \text{ Kg-m}^2.$$

II. INNER GIMBAL

The elements that make up the inner gimbal inertia are the plate, posts, pot mount, inner gimbal driven gear and the hat (see figure D-1). Again, the moment of inertia of the hat will not be computed directly. The moments of the plate and posts need not be recomputed due to symmetry.

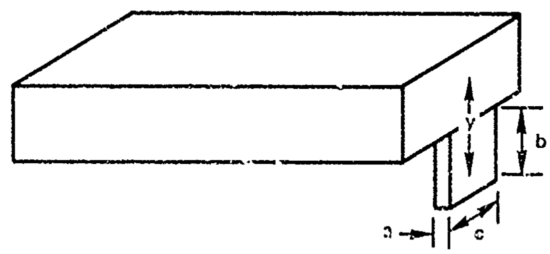
J. Pot Mount

$a = .00508$ m

$b = .0254$ m

$c = .0381$ m

$y = .0254$ m



The moment of inertia about the center of mass (I_{CM}) is given by:

$$I_{CM} = m\left(\frac{b^2 + c^2}{12}\right)$$

$\underline{m = .0132735 \text{ Kg}}$ (from section I.C. pg D-3)

$$\therefore I_{CM} = (.0132735 \text{ Kg})\left(\frac{(.0254 \text{ m})^2 + (.0381 \text{ m}^2)}{12}\right) = 7.42174 \times 10^{-7} \text{ Kg-m}^2$$

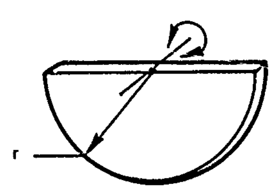
Then

$$I_z = I_{CM} + my^2$$

$$I_z = 7.42174 \times 10^{-7} \text{ Kg-m}^2 + (.0132735 \text{ Kg})(.0254 \text{ m})^2$$

$$\boxed{I_z = 1.088323 \times 10^{-5} \text{ Kg-m}^2}$$

K. Gear Drive



Since the center of rotation passes through the center of the diameter of the semicircle, the moment of inertia is given by:

$$I_z = m\frac{r^2}{2}$$

$\underline{m = .085155 \text{ Kg}}$ (from section I.E.1. pg D-5)

$r = .04953$ m

$$\therefore I_z = (.085155 \text{ Kg})\left[\frac{(.04953 \text{ m})^2}{2}\right]$$

$$\boxed{I_z = 1.04452 \times 10^{-4} \text{ Kg-m}^2}$$

III. TOTAL MOMENT OF INERTIA

I. Summary for Outer Gimbal

	Part	Mass (Kg)	Inertia (Kg-m^2)	Inertia oz-in-sec^2
A.	Plate	1.592823	3.16851×10^{-3}	.448661
B.	Posts	.062548	3.42828×10^{-4}	.048544
C.	Pot Mount	.0132735	8.1325×10^{-5}	.011516
D.	Support Blk	.0309716	2.20081×10^{-4}	.031163
E.	Gear	.085155	1.45072×10^{-4}	.020542
F.	Motor	.2575	9.515×10^{-4}	.134732
G.	Mount	.079641	5.87781×10^{-4}	.08323
H.	Bail Ring	.388859	3.96358×10^{-3}	.561243
I.	HAT	1.06	1.381986×10^{-2}	1.96037
	Total	3.57077	2.328054×10^{-2}	3.30

C. Summary for Inner Gimbal

	Part	Mass (Kg)	Inertia (Kg-m^2)	Inertia (oz-in-sec^2)
A.	Plate	1.592823	3.16851×10^{-3}	.448661
B.	Posts	.062548	3.42828×10^{-4}	.048544
J.	Pot Mount	.0132735	1.088323×10^{-5}	.0015411
K.	Gear	.085155	1.04452×10^{-4}	.0147904
I.	HAT	1.06	1.381986×10^{-2}	1.96037
	Total	2.8128	1.744653×10^{-2}	2.47

APPENDIX E
TIME-DOMAIN ANALYSIS OF AMPLIFIER/MOTOR/LOAD

This appendix derives the equations used for time-domain analysis of the servo drive system. The analysis was structured such that both the current drive and voltage drive systems could be evaluated with only changes to the input data for both versions of the time-domain computer programs (LaPlace Transform and Time Integration versions).

Figure E-2 presents comparative data between the two types of gimbal drive systems (current vs voltage) for both the inner and outer gimbals. The gimbal rate as a function of time is plotted for the comparative data. It is quite obvious from the curves that the current drive system is superior in response to that of the voltage drive system.

Two types of time-domain analysis were conducted to obtain the time-domain response data. The inverse LaPlace transform method, which is explained in detail in this section, was used to generate the comparative data for gear ratio optimization. The inverse LaPlace transform technique was very useful in obtaining the large amounts of data needed for the gear ratio optimization. Figures E-4 and E-5 illustrate the effects on the gimbal rate as a function of drive shaft gear ratio. It is quite obvious that a direct drive system is quite sluggish. As the gear ratio increases so does the gimbal response time – up to a point. As the gear ratio increases beyond some optimum value, the response starts to slow down. Figures E-6 and E-7 summarize the gear ratio optimization for the inner and outer gimbal system. The point to be noted about the inverse LaPlace transform technique is that it requires very little computer time to generate a large amount of time-domain data; thereby, being an economic means of generating this kind of data. The inverse LaPlace transform technique does not take into account the system nonlinearities. Therefore, a time integration program was written to incorporate the nonlinearities (limiters) that are shown in the diagram of figure E-1. The data presented in figures E-2 and E-3 was generated with the time integration computer program. Ref. 13 was used for the LaPlace transform analysis formulae.

Following is a derivation of the LaPlace transform methodology for generating time domain analysis for both the current and voltage servo drive systems.

13. Levy, EC, A New Table of LaPlace Transformation Pairs, The Book Page Company, Los Angeles, CA, 1963.

LAPLACE TRANSFORM TIME-DOMAIN ANALYSIS

I. BLOCK DIAGRAMS

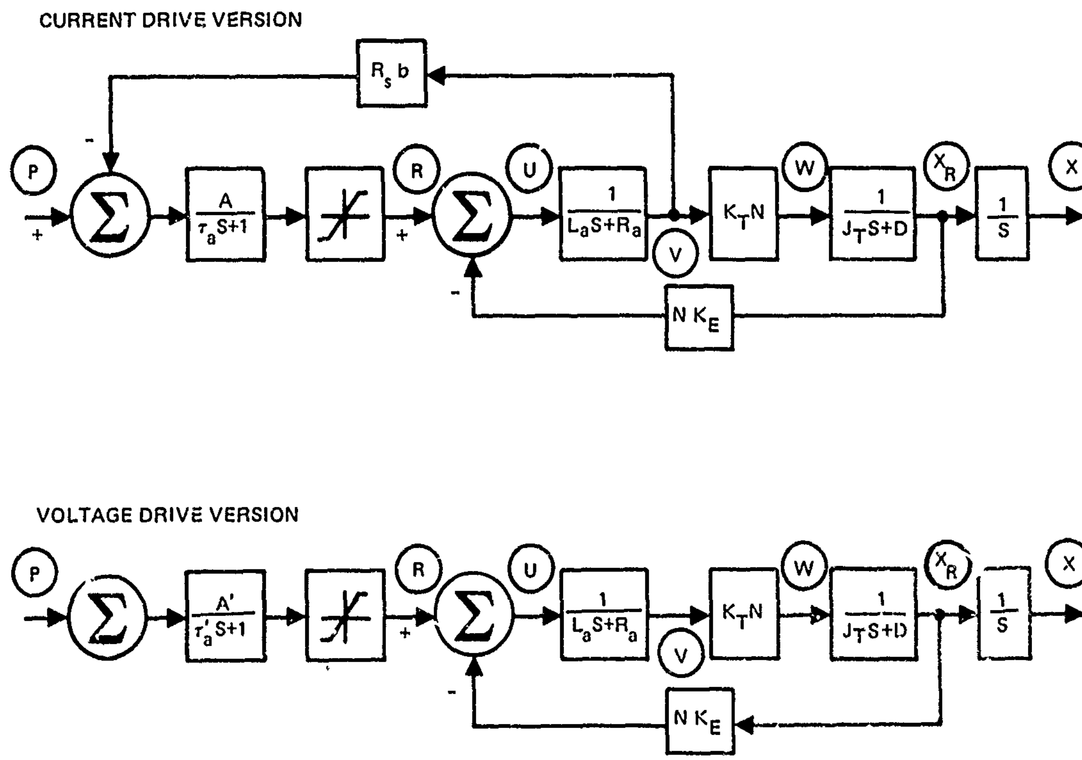


Figure E-1. Current and voltage block diagrams.

II. TRANSFER FUNCTIONS

a. Current drive version (rate output)

$$\frac{X_R}{P} = \frac{A\,K_T\,N}{(J_T\,S + D)\,(\tau_a\,S + 1)\,(L_a\,S + R_a) + A \cdot R_s\,b\,(J_T\,S + D) + N^2\,K_E\,K_T\,(\tau_a\,S + 1)}$$

or

$$\frac{X_R}{P} = \frac{A\,K_T\,N/L_a\,J_T\,\tau_a}{S^3 + \left(\frac{L_a\tau'_a D + J_T L_a + J_T \tau_a R_a}{L_a\,J_T\,\tau'_a}\right) S^2 + \left(\frac{D\,L_a + \tau_a D\,R_a + J_T R_a + A\,R_s b J_T + N^2 K_E K_T \tau_a}{L_a\,J_T\,\tau'_a}\right) S + \left(\frac{R_a\,D + A\,R_s\,b\,D + N^2\,K_E\,K_T}{La\,J_T\,\tau_a}\right)} \quad (1)$$

b. Voltage drive version (rate output)

$$\frac{X_R}{P} = \frac{A' K_T N}{(J_T S + D)(\tau_a' S + 1)(L_a S + R_a) + N^2 K_E K_T (\tau_a' S + 1)}$$

or

$$\frac{X_R}{P} = \frac{A' K_T N / L_a J_T \tau_a'}{S^3 + \left(\frac{L_a \tau'_a D + J_T L_a + J_T \tau_a' R_a}{L_a J_T \tau_a}\right) S^2 + \left(\frac{D L_a + \tau_a' D R_a + J_T R_a + N^2 K_E K_T \tau_a'}{L_a J_T \tau_a'}\right) S + \left(\frac{R_a D + N^2 K_E K_T}{L_a J_T \tau_a'}\right)} \qquad (2)$$

III. DESCRIPTION OF GAINS AND TIME CONSTANTS

A – Amplifier gain (v/v)

τ_a – Amplifier time constant (sec.)

L_a – Motor inductance (henries)

R_a – Armature resistance (ohms)

R_{sb} – Current feedback sensing resistor (ohms)

K_T – Torque sensitivity (oz-in/amp)

N – Gear ratio (gimbal-to-motor)

J_T – Total inertia. This is given by $J_T = N^2 J_M + J_L$ where J_M is the motor inertia and J_L is the load inertia

D – Friction (oz-in-sec) (viscous friction)

K_E – Back EMF (v/rad/sec)

A' – Amplifier gain for voltage driven motor.
Referring to the properties of an inverting op amp

$$A' = \frac{1-\beta}{\beta} \text{ where } \beta = \frac{R_1}{R_1 + R_f}$$

and R_1 is the input resistor, R_f is the feedback resistor. Choosing nominal values of $R_1 = 5K$ and $R_f = 20K$ yields a β of .2 and $A' = 4.0$.

τ_a' – Time constant for voltage driven motor. Again referring to properties of inverting op amps

$$\tau_a' = \frac{\tau_a}{1 + \beta A}$$

Note that, with the appropriate calculation of A' and τ_a' the voltage drive transfer function is the same as the current drive with $R_s b = 0.0$.

IV. METHOD OF OBTAINING TIME RESPONSE

A hand check of the poles of equations (1) and (2), using preliminary gains and time constants, showed that the roots could get quite large (negatively). This fact eliminates numberical integration as an efficient cost effective method of calculating the time response, due to the extremely small integration interval needed to show the effects of the large roots. Thus, the LaPlace transform method was chosen.

Both the current drive (1) and voltage drive (2) transfer functions contain cubic functions of S in the denominator (for the rate output). To obtain the position output, (1) and (2) must be multiplied by 1/S. Finally, to obtain the response to a unit step input, (1) and (2) must again be multiplied by 1/S.

Therefore, we have two basic forms for the denominator: a cubic multiplied by S for rate output with unit step input and a cubic multiplied by S^2 for position output with unit step input. In order to comply with standard forms of LaPlace transform pairs, we must divide these forms into two cases. Case 1 occurs when the cubic equation has three real roots and Case 2 when there are one real root and two conjugate complex roots.

V. LAPLACE TRANSFORM PAIRS

a. Three real root case

1. Rate output

$$F(s) = \frac{1}{S(1 + T_1 S)(1 + T_2 S)(1 + T_3 S)} \tag{3}$$

$$f(t) = 1 - \frac{T_1^2}{(T_1 - T_2)(T_1 - T_3)} e^{-t/T_1} - \frac{T_2^2}{(T_2 - T_1)(T_2 - T_3)} e^{-t/T_2} - \frac{T_3^2}{(T_3 - T_1)(T_3 - T_2)} e^{-t/T_3} \tag{4}$$

2. Position output

$$F(s) = \frac{1}{S^2 (1 + T_1 S)(1 + T_2 S)(1 + T_3 S)} \tag{5}$$

$$f(t) = t - (T_1 + T_2 + T_3) - \frac{1}{(T_1 - T_2)(T_2 - T_3)(T_3 - T_1)} \left[T_1^3 (T_2 - T_3) e^{-t/T_1} + T_2^3 (T_3 - T_1) e^{-t/T_2} + T_3^3 (T_1 - T_2) e^{-t/T_3} \right] \tag{6}$$

b. One real, two complex root case

1. Rate output

$$F(s) = \frac{1}{S(1+TS)\left(1+\frac{2\zeta}{\omega}S+\frac{1}{\omega^2}S^2\right)} \tag{7}$$

$$f(t) = 1 - \frac{T^2\omega^2}{1-2T\zeta\omega+T^2\omega^2}e^{-t/T} + \frac{\sin\left(\omega\sqrt{1-\zeta^2}\,t-\psi_R\right)}{\sqrt{1-\zeta^2}\,(1-2\zeta T\omega+T^2\omega^2)^{1/2}}e^{-\zeta\omega t} \tag{8}$$

where

$$\psi_R = \tan^{-1}\left(\frac{\sqrt{1-\zeta^2}}{-\zeta}\right) + \tan^{-1}\left(\frac{T\omega\sqrt{1-\zeta^2}}{1-T\zeta\omega}\right)$$

2. Position output

$$F(s) = \frac{1}{S^2(1+TS)\left(1+\frac{2\zeta}{\omega}S+\frac{1}{\omega^2}S^2\right)} \tag{9}$$

$$f(t) = t - T - \frac{2\zeta}{\omega} + \frac{T^3\omega^2}{1-2\zeta T\omega+T^2\omega^2}e^{-t/T} + \frac{\sin\left(\omega\sqrt{1-\zeta^2}\,t-\psi_p\right)}{\omega\left[(1-\zeta^2)(1-2\zeta T\omega+T^2\omega^2)\right]^{1/2}}e^{-\zeta\omega t} \tag{10}$$

where

$$\psi_p = 2\tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta} + \tan^{-1}\frac{T\omega\sqrt{1-\zeta^2}}{1-T\zeta\omega}$$

c. Note that, in all cases, $f(t) = \mathcal{L}^{-1}(F(s))$. Also, the cubic equations in (1) and (2) must be put into the form of the appropriate F(s) in order to evaluate the inverse LaPlace transform. Gain terms (numerator) in (1) and (2) multiply f(t) since the LaPlace transform is linear.

VI. FINDING THE ROOTS OF THE CUBIC

Any calculation, involving real numbers, done on a digital computer results in an approximation to the desired result due to truncation. Due to the large numbers encountered in the transfer functions under consideration, this approximation was not a good one. This was caused by addition and subtraction of very large numbers that had their first few significant digits in common.

Since the closed form solution of the cubic did not yield satisfactory results, a check was made using Newton's method. It was found that this method converged rapidly and yielded a better approximation to the actual roots.

A subroutine was written to find the roots of a cubic polynomial using Newton's method. The algorithm used can be found in "Elementary Numerical Analysis: an Algorithmic Approach" by Conte and de Boor, McGraw-Hill, 1972, pg 69. Essentially the algorithm uses Newton's method to find one real root of the cubic, where successive values of the polynomial and its derivative are calculated using nested multiplication. This method yields the coefficients of the quotient quadratic which can be solved to find the other two roots. Whether these roots are real or complex is indicated by a flag.

VII. TRANSFORMING THE TRANSFER FUNCTIONS INTO THE FORM USED IN THE LAPLACE TRANSFORM PAIRS

a. The transfer functions for both the current and voltage drive versions are of the form

$$F(s) = \frac{G'}{S^3 + pS^2 + qS + r},$$

where G' is the gain term $A\,K_T\,N/L_a\,\tau_a\,J_T$ or $A'\,K_T\,N/L_a\,\tau_a'\,J_T$. These must be put into the form used in the LaPlace transform pairs. Two cases are necessary depending on whether there are three real roots, or one real, two complex.

b. Three real root case

The transfer function

$$F(s) = \frac{G'}{S^3 + pS^2 + qS + r}$$

where

$$G' = \frac{A\,K_T\,N}{L_a\,\tau_a\,J_T} \quad \text{or} \quad \frac{A'\,K_T\,N}{L_a\,\tau_a'\,J_T}$$

must be changed to the form

$$F(s) = \frac{G}{(1 + T_1\,S)\,(i + T_2\,S)\,(1 + T_3\,S)}\,.$$

Let R_1, R_2 and R_3 be the real roots of the denominator. Then we can write

$$F(s) = \frac{G'}{(S - R_1)\,(S - R_2)\,(S - R_3)}\,.$$

$$F(s) = \frac{G'}{-R_1\,R_2\,R_3\,(1 + S/{-R_1})\,(1 + S/{-R_2})\,(1 + S/{-R_3})}$$

Let $T_1 = -\frac{1}{R_1}$, $T_2 = -\frac{1}{R_2}$ and $T_3 = -\frac{1}{R_3}$.

Then

$$F(s) = \frac{G' T_1 T_2 T_3}{(1 + T_1 S)(1 + T_2 S)(1 + T_3 S)} .$$

and we have

$$F(s) = \frac{G}{(1 + T_1 S)(1 + T_2 S)(1 + T_3 S)}$$

where

$$G = \frac{A K_T N \cdot T_1 T_2 T_3}{L_a \tau_a J_T} \quad \text{or} \quad \frac{A' K_T N T_1 T_2 T_3}{L_a \tau_a' J_T}$$

$$T_1 = -\frac{1}{R_1}$$

$$T_2 = -\frac{1}{R_2}$$

$$T_3 = -\frac{1}{R_3}$$

Now equation (4) can be used to ascertain the rate output time response, and equation (6) for the position output time response.

c. One real, two complex root case

The transfer function

$$F(s) = \frac{G'}{S^3 + pS^2 + qS + r}$$

where

$$G' = \frac{A K_T N}{L_a \tau_a J_T} \quad \text{or} \quad \frac{A' K_T N}{L_a \tau_a' J_T}$$

must be changed to the form

$$F(s) = \frac{G}{(1 + TS)\left(1 + \frac{2\zeta}{\omega} S + \frac{1}{\omega^2} S^2\right)} .$$

Let R and $\alpha \pm \beta i$ be the roots of the denominator. Then we can write

$$F(s) = \frac{G'}{(S - R)\,[S - (\alpha + \beta i)]\,[S - (\alpha - \beta i)]}$$

Let $T = -\frac{1}{R}$, then

$$F(s) = \frac{G' T}{(1 + TS)\,[S^2 - 2\alpha S + (\alpha^2 + \beta^2)]}$$

$$F(s) = \frac{G' T}{(1 + TS)\,(\alpha^2 + \beta^2)\left(1 - \frac{2\alpha}{\alpha^2 + \beta^2} S + \frac{1}{\alpha^2 + \beta^2} S^2\right)}$$

Let $\omega^2 = \alpha^2 + \beta^2$, $\zeta = -\frac{\alpha}{\omega}$ and $G = G'T/\omega^2$.

Then

$$F(s) = \frac{G}{(1 + TS)\left(1 + \frac{2\zeta}{\omega} S + \frac{1}{\omega^2} S^2\right)}$$

where

$$T = -\frac{1}{R}$$

$$\omega^2 = \alpha^2 + \beta^2$$

$$\zeta = -\frac{\alpha}{\omega}$$

$$G = \frac{A\,K_T\,N\,T}{L_a\,J_T\,\tau_a\,\omega^2} \text{ or } \frac{A'\,K_T\,N\,T}{L_a\,J_T\,\tau_a'\,\omega^2}$$

VIII. ALGORITHM FOR COMPUTING TIME RESPONSE OF AMPLIFIER/MOTOR/LOAD

a.
1. Read all gains and time constants, stop time and time increment.
2. Compute p, q and r, the coefficients .. .. cubic polynomial that make up the denominator of the polynomial.
3. Call subroutine to compute roots of the cubic
4. If (one real, two complex roots: r, $\alpha \pm \beta i$) then
5.   Compute T, ω, ζ, G, ψ_R, ψ_p
6.   While time $\leqslant$ stop time do
7.   increment time (t)
8.   compute rate and position using eq (8) & (10)
9.   output
10.   end do
11. else (three real root case)

```
12.       compute T1, T2, T3 & G
13.       while time ≤ stop t do
14.            increment time (t)
15.            compute rate and position using eq (4) & (6)
16.            output
17.       end do
18.   end if
19.   stop
```

b. Notes:

1. Notice that the algorithm does not refer to current or voltage drive. The choice of types of drive is made by appropriately setting the input variables. Set A to A′, τ_a to τ_a' and R_s b to 0.0. See Section III.

2. The algorithm was implemented in FORTRAN. In the implementation, the names of the variables correspond to the variables used in this write-up (eg, ZETA = ζ, OMEGA2 = ω^2, T = t, TT = T etc.)

3. The subroutine cubic referred to in step 3 returns three values, R_1 R_2 & R_3, and a flag. If the flag = 1 then R_1 is the real root R in Section VII.c. and $R_2 = \alpha$, $R_3 = \beta$. If the flag = 0 then R_1 R_2 & R_3 are the three real roots referred to in Section VII.b.

4. In the implementation, intermediate variables are used to store portions of the inverse LaPlace transform formulas (4), (6), (8), (10). Eg, TRM1 = 1 $- 2T\zeta\omega + T^2\omega^2$. This is done to reduce the size of the assignment statements for rate and position and to reduce the number of computations done in the loop.

TIME INTEGRATION TIME-DOMAIN ANALYSIS

The time integration methodology was required to take into account the nonlinearities of the system. The drawback of this analysis procedure is the cost in running the computer model. Basically the time integration methodology takes an n^{th} order differential equation and breaks it down into n first order differential equations or in other words the system is defined by a system of state variables[1]. The system of first order differential equations defining the servo drive system is summarized on figure E-8. These equations are integrated by an integration routine every sampling period.

Figure E-8 is a block diagram of the servo drive system which is a math model used to formulate the system of "first order" differential equations used in the time-domain analysis (time integration) computer program.

Computer Program listings and sample of output data for both the LaPlace and time integration analysis procedures are included in the following section LADSS*AMLTR and LADSS*AML 201.

1. State variables may be defined as the minimum set of variables that provide full knowledge of the system's behavior.

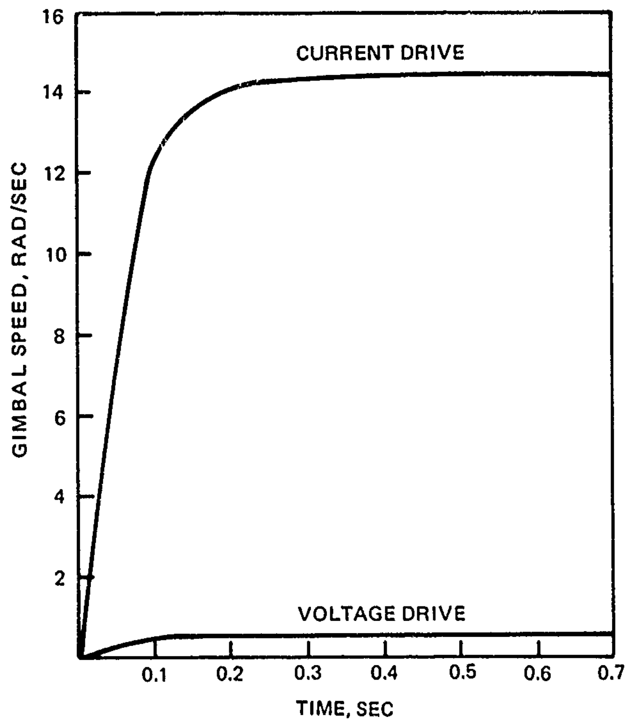


Figure E-2. Time response – comparison between voltage and current drives for inner gimbal.

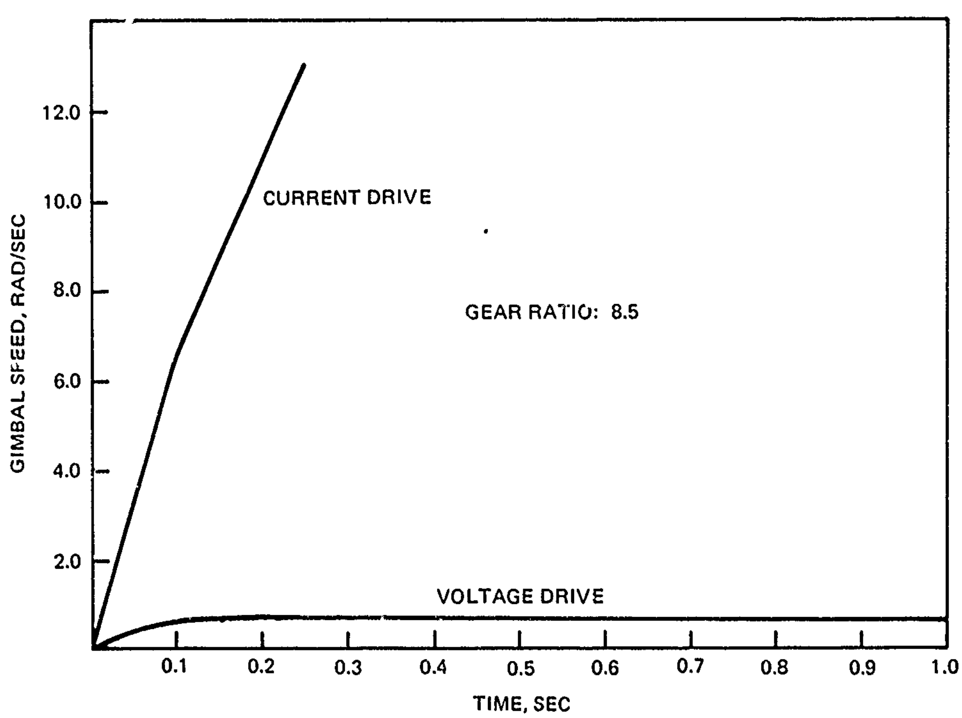


Figure E-3. Amplifier/motor load time response comparison between voltage and current drives for outer gimbal.

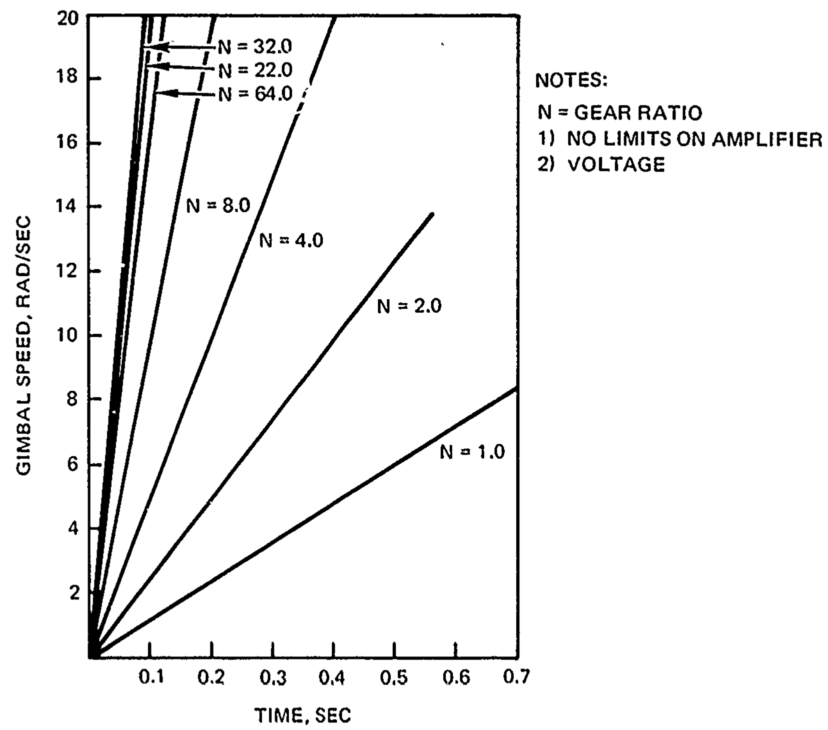


Figure E-4. Amplifier/motor/load time response as function of gear ratio (inner gimbal current drive).

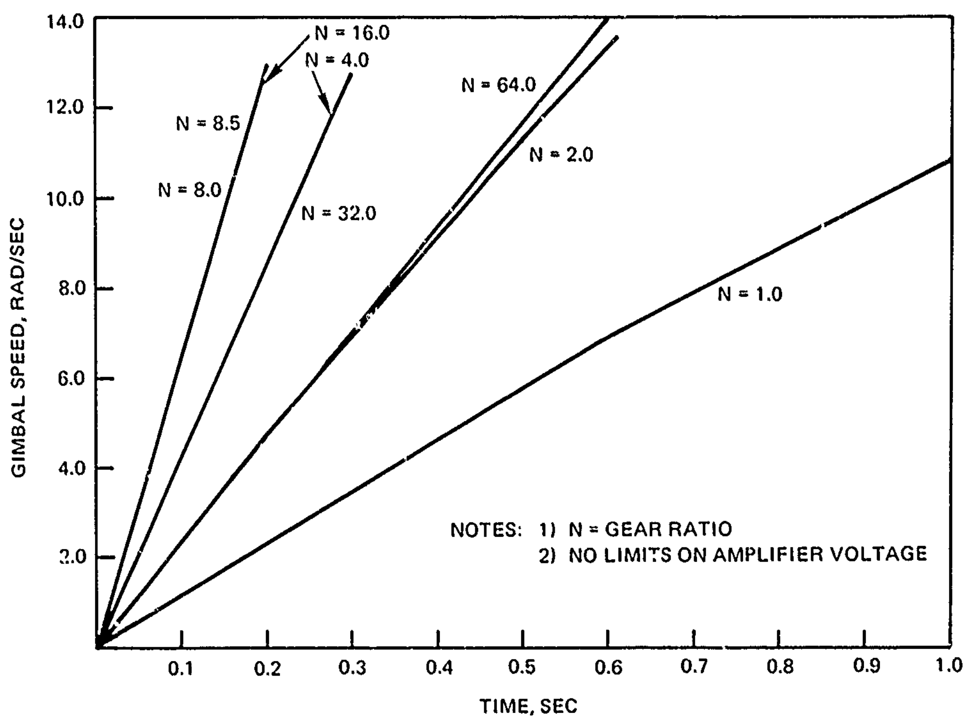


Figure E-5. Amplifier/motor/load time response as function of gear ratio (outer gimbal current drive).

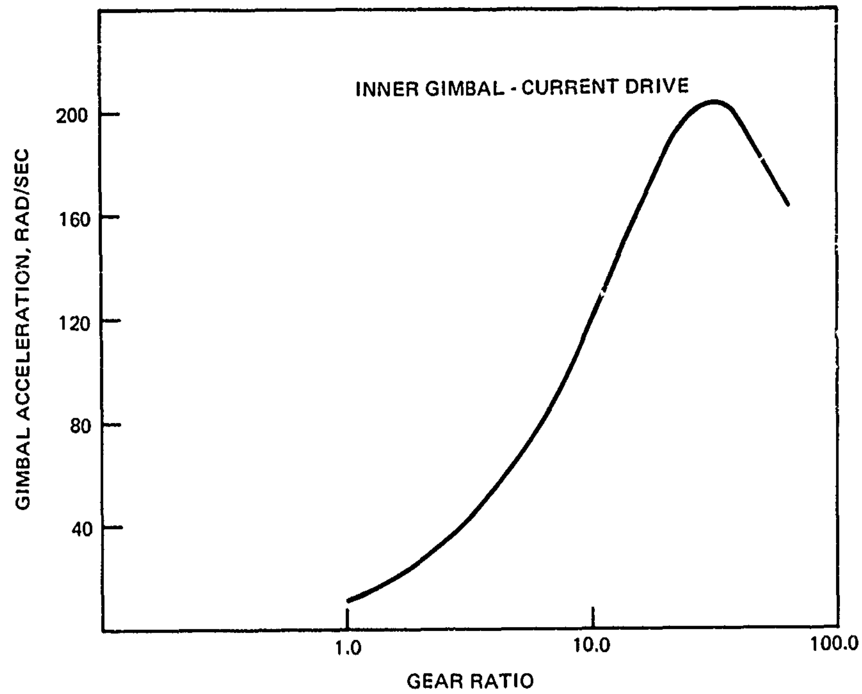


Figure E-6. Gear ratio vs acceleration – inner gimbal – current drive.

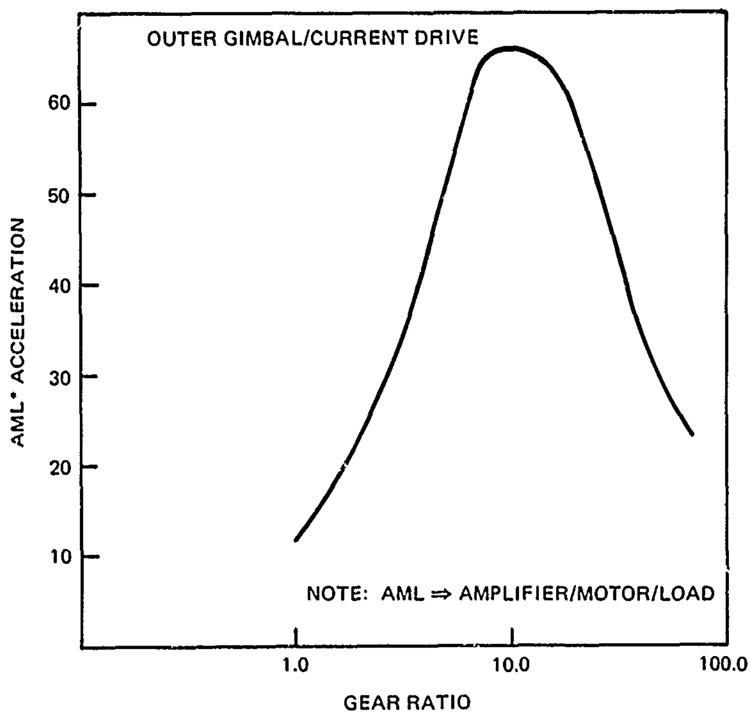
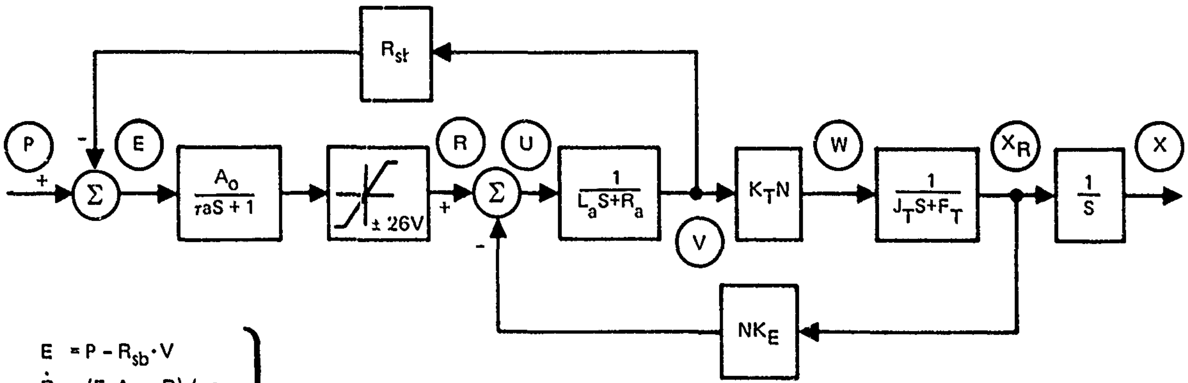


Figure E-7. Gear ratio vs acceleration – outer gimbal/current drive.



$$\left.\begin{aligned}
E &= P - R_{sb}\cdot V \\
\dot{R} &= (E\cdot A_o - R)/\tau a \\
U &= R - N\cdot K_E\cdot X_R \\
\dot{V} &= (U - V\cdot R_a)/L_a \\
W &= V\cdot K_T\cdot N \\
\dot{X}_R &= (W - X_R\cdot F_T)/J_T \\
\dot{X} &= X_R
\end{aligned}\right\}$$

FIRST ORDER DIFFERENTIAL EQUATIONS USED TO GENERATE THE TIME INTEGRATION TIME RESPONSE IN COMPUTER PROGRAM LADSS*AML301.

Figure E-8. Block diagram/equations of servo drive system/load for time integration computer program

LADSS* AMLTR

```
@FTN,RODS R.MAIN
FTN 8R1  *04/17/80-09:10:16,)
C**  NAME: LADSS STABILIZED PLATFORM AMPLIFIER/MOTOR/LOAD TIME RESPONSE
C**
C**  USAGE:  THE FOLLOWING CONTROL CARDS WILL EXCUTE THIS PROGRAM
C**    @XQT LADSS*AMLTR.PROG
C**    @ADD LADSS*AMLTR.(APPROPRIATE DATA ELEMENT)
C**
C**  PURPOSE:  THIS PROGRAM MODELS (IN THE TIME DOMAIN)
C**    THE AMPLIFIER/MOTOR/LOAD PORTION OF THE LADSS
C**    STABILIZED PLATFORM. THE TIME RESPONSE IS OBTAINED
C**    BY CALCULATING THE INVERSE LAPLACE TRANSFORM OF THE
C**    A/M/L TRANSFER FUNCTION.
C**
C**  LIMITATIONS: NONE
C**
C**  WARNINGS: NONE
C**
C**  SUBPROGRAMS REQIRED:
C**    CUBIC - COMPUTES THE ROOTS OF A CUBIC POLINOMIAL
C**
C**  ARGUMENTS: NONE
C**
C**  NOTES:
C**    1. THIS PROGRAM RUNS ON THE UNIVAC 1110 IN ASCII FORTRAN
C**       CAU TIME IS APPROXIMATELY ( NUM / 100 )  SECONDS
C**       NO. OF PAGES OF OUTPUT IS APPROXIMATELY ( .06 * NUM )
C**    2. EACH INPUT VARIABLE MUST BE ON A SEPARATE LINE WITH 7 SPACES
C**       AVAILABLE AT THE BEGINNING OF THE LINE FOR THE VARIABLE NAME
C**    3. THE INPUT TO THE A/M/L IS A UNIT STEP FUNCTION.
C**       THIS IS DUE TO THE CHOICE OF LAPLACE TRANSFORM PAIRS
C**       THAT ARE USED.
C**    4. TWO TYPES OF SYSTEMS CAN BE MODELED BY THIS PROGRAM.
C**       A) A VOLTAGE DRIVEN MOTOR
C**       B) A CURRENT DRIVEN MOTOR
C**       THE CURRENT DRIVEN VERSION IS OBTAINED BY
C**       SETTING INPUT VARIABLE RSB TO THE SENSING RESISTOR VALUE.
C**       TO GET THE VOLTAGE DRIVEN RESPONSE SET RSB TO 0.0
C**       AND ADJUST INPUT PARAMETERS A & TAUA AS INDICATED IN WRITE UP
C**    5. THE AMPLIFIER IS A CURRENT OR VOLTAGE DRIVEN AMPLIFIER.
C**       THE DC TORQUE MOTOR IS A PERMANENT MAGNET, ARMATURE
C**          CONTROLLED DEVICE.
C**       THE LOAD IS THE ANTENNA PLUS MOTOR INERTIA REFERENCED
C**          TO THE GIMBAL SHAFT.
C**
C**  PROGRAMMER/ORGANIZATION: DARYL E. SMITH  CSC DEPT 551
C**
C**  ALGORITHM:
C**    1. READ AND ECHO INPUTS
C**    2. COMPUTE COEFFICIENTS OF CUBIC POLYNOMIAL
C**    3. CALL CUBIC TO FIND ROOTS
C**    4. COMPUTE VARIABLES USED IN INVERSE LAPLACE TRANSFORM
C**       EVALUATION
C**    5. DO FOR 'NUM' TIME INCREMENTS
C**          EVALUATE INVERSE LAPLACE TRANSFORMS
C**          OUTPUT
C**       END DO
```

```
C..      6. STOP
C..
C..  RECORD OF MODIFICATIONS.
       START EDIT PAGE

```

```
      REAL      A        @ AMPLIFIER GAIN  V/V
      REAL*8    ALPHA    @ REAL PART OF CUBIC ROOT
      REAL*8    BETA     @ IMAGINARY PART OF CUBIC ROOT
      REAL      D        @ MOTOR FRICTION  OZ-IN-SEC
      REAL*8    GAIN     @ COMPLETE TRANSFER FUNCTION GAIN
      INTEGER   I        @ LOOP COUNTER
      INTEGER   ITER     @ MAX. NO. ITERATIONS ALLOWED IN CUBIC
C                          SUBROUTINE ( ITER .GE. 10 ).
C                          ON RETURN FROM CUBIC, IF ITER=0, NEWTON'S
C                          METHOD DID NOT CONVERGE & NO ROOTS WERE FOUND
      REAL      JL       @ LOAD INERTIA  OZ-IN-SEC**2
      REAL      JM       @ MOTOR INERTIA  OZ-IN-SEC**2
      REAL      JT       @ TOTAL INERTIA  OZ-IN-SEC**2
      REAL      KE       @ BACK EMF  V/RAD/SEC
      INTEGER   KFLG     @ FLAG RETURNED FROM SUBROUTINE CUBIC
C                          KFLG = 0 => 3 REAL ROOTS
C                          KFLG = 1 => 1 REAL, 2 COMPLEX ROOTS
      REAL      KT       @ TORQUE SENSITIVITY  OZ-IN/AMP
      REAL      LA       @ MOTOR INDUCTANCE  HENRIES
      REAL      N        @ GEAR RATIO (GIMBAL-TO-MOTOR)
      INTEGER   NUM      @ NUMBER OF TIMES TO EVALUATE
      REAL*8    OMEGA    @ SEE DOCUMENTATION
      REAL*8    OMEGA2   @ SEE DOCUMENTATION
      REAL*8    OMZ2     @ SEE DOCUMENTATION
      REAL*8    P        @ COEFFICIENT OF SQUARE TERM IN CUBIC
      REAL*8    PHIP     @ SEE DOCUMENTATION
      REAL*8    PHIR     @ SEE DOCUMENTATION
      REAL*8    POSTN    @ POSITION OUTPUT  RAD
      REAL*8    Q        @ COEFFICIENT OF S TERM IN CUBIC
      REAL*8    R        @ CONSTANT TERM IN CUBIC
      REAL      RA       @ ARMATURE RESISTANCE  OHMS
      REAL*8    RATE     @ RATE OUTPUT  RAD/SEC
      REAL*8    ROMZ2    @ SEE DOCUMENTATION
      REAL*8    RR       @ REAL ROOT OF CUBIC
      REAL*8    RR1      @ ROOTS OF CUBIC.  IF KFLG = 0,
      REAL*8    RR2      @    THERE ARE 3 REAL ROOTS, IF KFLG = 1,
      REAL*8    RR3      @    THERE ARE 1 REAL & 2 COMPLEX
      REAL      RSB      @ SENSING RESISTOR VALUE  OHMS
      REAL      STOPT    @ STOP TIME (SIMULATED)
      REAL      T        @ SIMULATED TIME
      REAL      TAUA     @ AMPLIFIER TIME CONSTANT  SEC
      REAL      TINC     @ TIME INCREMENT
      REAL*8    TRM1     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM2     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM3     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM4     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM5     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM6     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM7     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TRM8     @ STORAGE FOR INTERMEDIATE VALUES
      REAL*8    TT       @ SEE DOCUMENTATION
      REAL*8    TT1      @ 1.0 / ( -RR1 )
      REAL*8    TT2      @ 1.0 / ( -RR2 )
      REAL*8    TT3      @ 1.0 / ( -RR3 )
      REAL*8    TTSQ     @ TT**2
      REAL*8    ZETA     @ SEE DOCUMENTATION
      START EDIT PAGE
```

```
      READ ( 5,100 ) A,TAUA,LA,RA,RSB,KT,N,JM,JL,D,KE
100   FORMAT ( 7X,F10.0 )
      READ ( 5,200 ) NUM,TINC,ITER
200   FORMAT ( I5,F10.0,I5 )
      JT = N*N*JM + JL
      WRITE (6,300 ) A,TAUA,LA,RA,RSB,KT,N,JM,JL,JT,D,KE
300   FORMAT ( ' A      ',F10.3,/,' TAUA ',F10.5,/,' LA    ',F10.5,/,
     &         ' RA     ',F10.5,/,' RSB  ',F10.5,/,' KT    ',F10.5,/,
     &         ' N      ',F10.5,/,' JM   ',F10.5,/,' JL    ',F10.5,/,
     &         ' JT     ',F10.5,/,' D    ',F10.5,/,' KE    ',F10.5 )
      P = ( LA*TAUA*D + JT*LA + JT*TAUA*RA ) / ( LA*JT*TAUA )
      Q = ( D*LA + TAUA*D*RA + JT*RA + A*RSB*JT + N*N*KE*KT*TAUA ) /
     &    ( LA*JT*TAUA )
      R = ( RA*D + A*RSB*D + N*N*KE*KT ) / ( LA*JT*TAUA )
      WRITE ( 6,400 ) P,Q,R
400   FORMAT ( '0   P, Q, R: ',3 ( D20.12,3X ) )
      CALL CUBIC ( P,Q,R,ITER,KFLG,RR1,RR2,RR3 )
      IF ( ITER .EQ. 0 ) THEN
         NUM = 0
      END IF
      IF ( KFLG .EQ. 1 ) THEN
C
C   ONE REAL, TWO COMPLEX ROOT CASE
C
         ALPHA = RR2
         BETA = RR3
         RR = RR1
         WRITE ( 6,500 ) RR,ALPHA,BETA
500      FORMAT ( '0   ONE REAL ROOT, TWO COMPLEX ROOTS',/,
     &      '0   RR, ALPHA, BETA: ',3 ( D20.12,3X ) )
         TT = 1.0D0 / ( -RR )
         TTSQ = TT * TT
         OMEGA2 = ALPHA*ALPHA + BETA*BETA
         OMEGA = DSQRT ( OMEGA2 )
         ZETA = - ( ALPHA / OMEGA )
         OMZ2 = 1.0D0 - ZETA*ZETA
         ROMZ2 = DSQRT ( OMZ2 )
         TRM1 = 1.0D0 - 2.0D0*TT*ZETA*OMEGA + TTSQ*OMEGA2
         TRM2 = DSQRT ( TRM1 )
         TRM3 = ( TT*OMEGA*ROMZ2 ) / ( 1.0D0 - TT*ZETA*OMEGA )
         PHIR = DATAN ( ROMZ2 / ( -ZETA ) ) + DATAN ( TRM3 )
         PHIP = 2.0D0*DATAN ( ROMZ2 / ( -ZETA ) ) + DATAN ( TRM3 )
         GAIN = ( A*KT*N*TT ) / ( LA*JT*TAUA*OMEGA2 )
         WRITE ( 6,600 ) TT,OMEGA,TRM1,TRM2,TRM3,GAIN,ZETA
600      FORMAT ( '0   TT: ',D20.12 ,/,
     &      '0   OMEGA, TRM1, TRM2, TRM3:  ',4 ( D20.12,3X ) ,/,
     &      '0   GAIN = ',D20.12,10X,' ZETA = ',D20.12 )
         STOPT = FLOAT ( NUM ) * TINC
         WRITE ( 6,700 ) NUM,TINC,STOPT,ITER
700      FORMAT ( '0  NUM = ',I5,5X,'TINC = ',F10.5,5X,'STOPT = ',F10.5,
     &      /,'0   ITER = ',I5 )
         WRITE ( 6,800 ) PHIR,PHIP
800      FORMAT ( '0   PHIR = ',D20.12,5X,'PHIP = ',D20.12 )
         DO 1000 I=1,NUM
            T = TINC * FLOAT ( I )
            TRM4 = DEXP ( ( -T ) / TT )
            TRM5 = DEXP ( -ZETA*OMEGA*T )
```

```
2                   TRM6 = OMEGA * ROMZ2 * T
2                   TRM7 = DSIN ( TRM6 - PHIR )
2                   TRM8 = DSIN ( TRM6 - PHIP )
2                   RATE = 1.0D0 - ( ( ( TTSQ*OMEGA2 ) / TRM1 ) * TRM4 ) +
2          &            ( ( TRM5 * TRM7 ) / ( ROMZ2 * TRM2 ) )
2                   RATE = RATE * GAIN
2                   POSTN = T - TT - ( ( 2.0D0*ZETA ) / OMEGA ) +
2          &            ( ( ( TTSQ*TT*OMEGA2 ) / TRM1 ) * TRM4 ) +
2          &            ( ( TRM5 * TRM8 ) / ( OMEGA*OMZ2*TRM2 ) )
2                   POSTN = POSTN * GAIN
2                   WRITE ( 6,900 ) T,RATE,POSTN,TRM4,TRM5,TRM6
2     900           FORMAT ( '0TIME =',F8.4,8X,'RATE = ',G12.5,8X,'POSITION = ',
2          &               G12.5,/,' ',15X,'TRM4,TRM5,TRM6: ',3 ( G12.5,3X ) )
2     1000     CONTINUE
2     C
1           ELSE
1     C
1     C   THREE REAL ROOT CASE
1     C
1              WRITE ( 6,1100 ) RR1,RR2,RR3
1     1100     FORMAT ( '0   THREE REAL ROOTS',/,
1          &           '0   RR1,RR2,RR3: ',3 ( D20.12,3X ) )
1              TT1 = 1.0D0 / ( -RR1 )
1              TT2 = 1.0D0 / ( -RR2 )
1              TT3 = 1.0D0 / ( -RR3 )
1              WRITE ( 6,1200 ) TT1,TT2,TT3
1     1200     FORMAT ( '0   TT1,TT2,TT3: ',3 ( D20.12,3X ) )
1              TRM1 = TT1 - TT2
1              TRM2 = TT1 - TT3
1              TRM3 = TT2 - TT3
1              GAIN = ( A*KT*N*TT1*TT2*TT3 ) / ( LA*JT*TAUA )
1              WRITE ( 6,1300 ) TRM1,TRM2,TRM3,GAIN
1     1300     FORMAT ( '0   TRM1,TRM2,TRM3: ',3 ( D20.12,3X ) ,/,
1          &           '0   GAIN = ',D20.12 )
1              DO 1400 I=1,NUM
2                   T = TINC * FLOAT ( I )
2                   TRM4 = DEXP ( ( -T ) / TT1 )
2                   TRM5 = DEXP ( ( -T ) / TT2 )
2                   TRM6 = DEXP ( ( -T ) / TT3 )
2                   RATE = 1.0D0 - ( ( TT1*TT1 ) / ( TRM1*TRM2 ) ) * TRM4 -
2          &            ( ( TT2*TT2 ) / ( -TRM1*TRM3 ) ) * TRM5 -
2          &            ( ( TT3*TT3 ) / ( TRM2*TRM3 ) ) * TRM6
2                   RATE = RATE * GAIN
2                   POSTN = T - ( TT1 + TT2 + TT3 ) -
2          &            ( 1.0D0 / ( TRM1*TRM3* ( -TRM2 ) ) ) *
2          &            ( TT1*TT1*TT1*TRM3*TRM4 +
2          &            TT2*TT2*TT2* ( -TRM2 ) * TRM5 +
2          &            TT3*TT3*TT3*TRM1*TRM6 )
2                   POSTN = POSTN * GAIN
2                   WRITE ( 6,900 ) T,RATE,POSTN,TRM4,TRM5,TRM6
2     1400     CONTINUE
1           END IF
            STOP 9999
            END
```

```
 @FTN,PODS R.CUBIC
 FTN 8R1  -04/17/80-09:10(14,)
            SUBROUTINE CUBIC ( P,               @ INPUT
      &                        Q,               @ INPUT
      &                        R,               @ INPUT
      &                        ITER,            @ INPUT/OUTPUT
      &                        KFLG,            @ OUTPUT
      &                        RR1,             @ OUTPUT
      &                        RR2,             @ OUTPUT
      &                        RR3 )            @ OUTPUT
C..
C..  USAGE: CALL CUBIC ( P,Q,R,ITER,KFLG,RR1,RR2,RR3 )
C..
C..  PURPOSE: THIS ROUTINE CALCULATES THE ROOTS OF THE CUBIC POLYNOMIAL
C..    X**3 + P * X**2 + Q * X + R = 0, BY NEWTONS METHOD.
C..
C..  LIMITATIONS: THE NEWTON ITERATION SCHEME WILL STOP AFTER ITER TIMES . .
C..
C..  WARNINGS: IF THE ITERATION SCHEME DOES NOT CONVERGE, A MESSAGE
C..     IS PRINTED, THEN CONTROL IS RETURNED TO THE CALLING PROGRAM
C..     THE RESULTS AT THIS TIME WILL BE ERRONEOUS.
C..
C..  SUBPROGRAMS REQUIRED: NONE
C..
C..  ARGUMENTS;
C..   INPUT:        P    - COEFFICIENT OF SQUARED TERM OF CUBIC
C..                 Q    - COEFFICIENT OF X TERM OF CUBIC
C..                 R    - CONSTANT TERM OF CUBIC
C..   INPUT/OUTPUT:  ITER - MAXIMUM NO. OF TIMES TO ITERATE.
C..                         IF ITERATION SCHEME DOES NOT CONVERGE IN
C..                         ITER TIMES, SET ITER TO 0.
C..   OUTPUT:       KFLG - FLAG TO INDICATE THE TYPE OF ROOTS FOUND.
C..                        KFLG = 0 - THREE REAL ROOTS
C..                        KFLG = 1 - ONE REAL, TWO COMPLEX
C..                 RR1  - REAL ROOT
C..                 RR2  - TWO CASES:
C..                        KFLG=0 - RR2 IS SECOND REAL ROOT
C..                        KFLG=1 - RR2 IS REAL PART OF COMPLEX ROOTS
C..                 RR3  - TWO CASES:
C..                        KFLG=0 - RR2 IS THIRD REAL ROOT
C..                        KFLG=1 - RR2 IS IMAG PART OF COMPLEX ROOTS
C..
C..  NOTES: ALL VARIABLES IN CUBIC ARE REAL*8 EXCEPT I,ITER,KFLG,
C..     THIS INCLUDES P,Q,R,RR1,RR2,RR3 IN THE CALL PARAMETERS
C..
C..  PROGRAMMER/ORGANIZATION; DARYL E. SMITH  CSC DEPT 551
C..
C..  ALGORITHM; NEWTONS METHOD IS USED TO FIND THE REAL ROOT.
C..     EVALUATION OF THE POLYNOMIAL AND ITS DERIVATIVE IS BY THE
C..     FACTORED METHOD.  IE.  ( ( X+P ) * X + Q ) * X + R
C..     IN PROGRAM VARIABLES - B2 = X+P,  B1 = Q + X*B2.
C..     THE RESOLVED QUADRATIC ( X**2 + B2*X + B1 = 0 ) IS THEN SOLVED
C..     USING THE QUADRATIC FORMULA.
C..
C..  RECORD OF MODIFICATIONS: .
      START EDIT PAGE
```

```
      REAL*8   B0          @ ALL P'S AND C'S ARE INTERMEDIATE
      REAL*8   B1          @ STORAGE FOR NEWTONS METHOD ITERATION.
      REAL*8   B2
      REAL*8   B3
      REAL*8   C1
      REAL*8   C2
      REAL*8   C3
      REAL*8   DESC        @ DESCRIMINANT OF RESOLVED QUADRATIC
      REAL*8   DX          @ CHANGE IN X AT EACH ITERATION DX=F(X)/F'(X)
      INTEGER  I           @ COUNTS NO. OF ITERATIONS
      INTEGER  ITER        @ MAX NO. OF ITERATIONS TO PERFORM.
C                            IF ITERATION SCHEME DOES NOT
C                            CONVERGE, SET ITER TO 0
      INTEGER  KFLG        @ INDICATES TYPE OF ROOTS
      REAL*8   P           @ COEFF. OF SQUARE TERM IN CUBIC
      REAL*8   Q           @ COEFF. OF X TERM IN CUBIC
      REAL*8   R           @ CONSTANT TERM IN CUBIC
      REAL*8   RR1         @ REAL ROOT
      REAL*8   RR2         @ REAL ROOT OR REAL PART OF COMPLEX ROOT
      REAL*8   RR3         @ REAL ROOT OR IMAG PART OF COMPLEX ROOT
      REAL*8   X           @ UNKNOW VARIABLE
      START EDIT PAGE
```

```
      I = 0
      X = -2.0D-1
      B3 = 1.0D0
      C3 = B3
 10   I = I + 1
      B2 = P + X*B3
      C2 = B2 + X*C3
      B1 = Q + X*B2
      C1 = B1 + X*C2
      B0 = R + X*B1
      DX = B0 / C1
      X = X - DX
      WRITE ( 6,20 ) X,DX,B0,B1,B2,C1,C2
 20   FORMAT ( '    X,DX,B0: ',3 ( D20.12,3X ) ,/,
     &  '    B1,B2,C1,C2: ',4 ( D20.12,3X ) )
C
C    CHECK FOR END OF ITERATION
C
      IF ( ( ABS ( DX ) .GE. 1.0D-10 ) .AND. ( I .LE. ITER ) ) GO TO 10
C
C    CHECK FOR CONVERGENCE
C
      IF ( I .LE. ITER ) THEN
C
C        CONVERGENCE; FIND ROOTS
C
         RR1 = X - DX
         DESC = B2*B2 - 4.0D0*B1
C
C            CHECK FOR POSITIVE DESCRIMINANT
C
         IF ( DESC .GE. 0.0D0 ) THEN
C
C                THREE REAL ROOTS
C
            RR2 = ( -B2 + DSQRT ( DESC ) ) / 2.0D0
            RR3 = ( -B2 - DSQRT ( DESC ) ) / 2.0D0
            KFLG = 0
         ELSE
C
C                ONE REAL & TWO COMPLEX
C
            RR2 = -B2 / 2.0D0
            RR3 = DSQRT ( -DESC ) / 2.0D0
            KFLG = 1
         END IF
      ELSE
C
C        NO CONVERGENCE
C
         WRITE ( 6,30 )
 30      FORMAT ( '0******** CUBIC ITERATION .GT. ITER ' )
         ITER = 0
      END IF
      RETURN
      END
```

```
LADSS*AMLIR(1).OCVLIDN
     1       A      =       1.0
     2       TAUA   =   .000001
     3       LA     =     .0014
     4       RA     =       3.0
     5       KSG    =       0.0
     6       KT     =      24.8
     7       N      =       8.5
     8       JM     =      .016
     9       JL     =      3.30
    10       D      =      .706
    11       KE     =      .177
    12         100          .01   20

@XQT R.PROG
```

```
A          1.000
TAUA       .00000
LA         .00140
KA        3.00000
KSL        .00000
KT       24.00000
N         2.50000
JM         .01600
JL        3.30000
JT        4.45600
D          .70600
KE         .17700

  F, W, R:      .100214300000+007        .214306678400+010        .511776409600+011
  X,DX,BC:     -.238850117656+002        .236650117656+002        .507490676889+011
  B1,B2,C1,C2:        .214266635544+010        .100214280000+007        .214266592692+010        .100214260000+007
  X,DX,BO:     -.241533247595+002        .268312993900+000        .562168338611+009
  B1,B2,C1,C2:        .211913115715+010        .100211911499+007        .209519610079+010        .100209522998+007
  X,DX,BC:     -.241533592000+002        .344404436635-004        .721409633617+005
  B1,B2,C1,C2:        .211886228205+010        .100211864668+007        .209465836348+010        .100209469335+007
  X,DX,BC:     -.241533592000+002        .567488947434-012        .118869543076-002
  B1,B2,C1,C2:        .211886224754+010        .100211884664+007        .209465829446+010        .100209469328+007

  THREE REAL ROOTS

  RR1,RR2,RR3:   -.241533592000+002      -.211886228067+004      -.999999984360+006

  TT1,TT2,TT3:    .414021085730-001       .471951390669-003       .100000001564-005

  TRM1,TRM2,TRM3:    .409301571823-001       .414011085730-001       .170951390653-003

  GAIN =    .660263263648+000

TIME =    .0100        RATE =    .13569+000       POSITION =    .67270-003
                 TRM4,TRM5,TRM6:    .78542+000       .62791-009       .00000

TIME =    .0200        RATE =    .24825+000       POSITION =    .26150-002
                 TRM4,TRM5,TRM6:    .61689+000       .39427-018       .00000

TIME =    .0300        RATE =    .33666+000       POSITION =    .55573-002
                 TRM4,TRM5,TRM6:    .48452+000       .24757-027       .00000

TIME =    .0400        RATE =    .40610+000       POSITION =    .92850-002
                 TRM4,TRM5,TRM6:    .36055+000       .15545-036       .00000

TIME =    .0500        RATE =    .46063+000       POSITION =    .13630-001
                 TRM4,TRM5,TRM6:    .29869+000       .97609-046       .00000

TIME =    .0600        RATE =    .50347+000       POSITION =    .18459-001
                 TRM4,TRM5,TRM6:    .23476+000       .61290-055       .00000

TIME =    .0700        RATE =    .53711+000       POSITION =    .23668-001
                 TRM4,TRM5,TRM6:    .18438+000       .38485-064       .00000

TIME =    .0800        RATE =    .56354+000       POSITION =    .29177-001
                 TRM4,TRM5,TRM6:    .14482+000       .24165-073       .00000
```

```
TIME =   .0900        RATE =   .58429+000      POSITION =   .34920-001
              TRM4,TRM5,TRM6:   .11374+000   .15173-082    .00000

TIME =   .1000        RATE =   .60060+000      POSITION =   .40848-001
              TRM4,TRM5,TRM6:   .89337-001   .95275-092    .00000

TIME =   .1100        RATE =   .61340+000      POSITION =   .46921-001
              TRM4,TRM5,TRM6:   .70168-001   .59824-101    .00000

TIME =   .1200        RATE =   .62345+000      POSITION =   .53107-001
              TRM4,TRM5,TRM6:   .55111-001   .37564-110    .00000

TIME =   .1300        RATE =   .63135+000      POSITION =   .59383-001
              TRM4,TRM5,TRM6:   .43266-001   .23587-119    .00000

TIME =   .1400        RATE =   .63756+000      POSITION =   .65728-001
              TRM4,TRM5,TRM6:   .33997-001   .14811-128    .00000

TIME =   .1500        RATE =   .64243+000      POSITION =   .72129-001
              TRM4,TRM5,TRM6:   .26702-001   .92998-138    .00000

TIME =   .1600        RATE =   .64626+000      POSITION =   .78573-001
              TRM4,TRM5,TRM6:   .20973-001   .58394-147    .00000

TIME =   .1700        RATE =   .64926+000      POSITION =   .85052-001
              TRM4,TRM5,TRM6:   .16472-001   .36666-156    .00000

TIME =   .1800        RATE =   .65162+000      POSITION =   .91557-001
              TRM4,TRM5,TRM6:   .12938-001   .23023-165    .00000

TIME =   .1900        RATE =   .65345+000      POSITION =   .98082-001
              TRM4,TRM5,TRM6:   .10162-001   .14457-174    .00000

TIME =   .2000        RATE =   .65493+000      POSITION =   .10462+000
              TRM4,TRM5,TRM6:   .79812-002   .90774-184    .00000

TIME =   .2100        RATE =   .65608+000      POSITION =   .11118+000
              TRM4,TRM5,TRM6:   .62666-002   .56998-193    .00000

TIME =   .2200        RATE =   .65697+000      POSITION =   .11775+000
              TRM4,TRM5,TRM6:   .49235-002   .35790-202    .00000

TIME =   .2300        RATE =   .65768+000      POSITION =   .12432+000
              TRM4,TRM5,TRM6:   .38670-002   .22473-211    .00000

TIME =   .2400        RATE =   .65823+000      POSITION =   .13090+000
              TRM4,TRM5,TRM6:   .30372-002   .14111-220    .00000

TIME =   .2500        RATE =   .65867+000      POSITION =   .13748+000
              TRM4,TRM5,TRM6:   .23855-002   .88604-230    .00000

TIME =   .2600        RATE =   .65901+000      POSITION =   .14407+000
              TRM4,TRM5,TRM6:   .18736-002   .55635-239    .00000

TIME =   .2700        RATE =   .65926 [illegible]0   POSITION =   .15066+000
              TRM4,TRM5,TRM6:   .14[illegible]-002   .34934-248    .00000
```

```
TIME =   .2800        RATE =   .65949+000       POSITION =   .15726+000
            TRM4,TRM5,TRM6:   .11558-002     .21955-257      .00000

TIME =   .2900        RATE =   .65966+000       POSITION =   .16385+000
            TRM4,TRM5,TRM6:   .90781-003     .13773-266      .00000

TIME =   .3000        RATE =   .65979+000       POSITION =   .17045+000
            TRM4,TRM5,TRM6:   .71302-003     .66466-276      .00000

TIME =   .3100        RATE =   .65989+000       POSITION =   .17705+000
            TRM4,TRM5,TRM6:   .56002-003     .54305-285      .00000

TIME =   .3200        RATE =   .65997+000       POSITION =   .18365+000
            TRM4,TRM5,TRM6:   .43965-003     .34099-294      .00000

TIME =   .3300        RATE =   .66003+000       POSITION =   .19025+000
            TRM4,TRM5,TRM6:   .34547-003     .21411-303      .00000

TIME =   .3400        RATE =   .66008+000       POSITION =   .19685+000
            TRM4,TRM5,TRM6:   .27134-003     .00000          .00000

TIME =   .3500        RATE =   .66012+000       POSITION =   .20345+000
            TRM4,TRM5,TRM6:   .21312-003     .00000          .00000

TIME =   .3600        RATE =   .66015+000       POSITION =   .21005+000
            TRM4,TRM5,TRM6:   .16739-003     .00000          .00000

TIME =   .3700        RATE =   .66018+000       POSITION =   .21665+000
            TRM4,TRM5,TRM6:   .13147-003     .00000          .00000

TIME =   .3800        RATE =   .66019+000       POSITION =   .22325+000
            TRM4,TRM5,TRM6:   .10326-003     .00000          .00000

TIME =   .3900        RATE =   .66021+000       POSITION =   .22986+000
            TRM4,TRM5,TRM6:   .81101-004     .00000          .00000

TIME =   .4000        RATE =   .66022+000       POSITION =   .23646+000
            TRM4,TRM5,TRM6:   .63699-004     .00000          .00000

TIME =   .4100        RATE =   .66023+000       POSITION =   .24306+000
            TRM4,TRM5,TRM6:   .50031-004     .00000          .00000

TIME =   .4200        RATE =   .66024+000       POSITION =   .24966+000
            TRM4,TRM5,TRM6:   .39295-004     .00000          .00000

TIME =   .4300        RATE =   .66024+000       POSITION =   .25627+000
            TRM4,TRM5,TRM6:   .30863-004     .00000          .00000

TIME =   .4400        RATE =   .66025+000       POSITION =   .26287+000
            TRM4,TRM5,TRM6:   .24241-004     .00000          .00000

TIME =   .4500        RATE =   .66025+000       POSITION =   .26947+000
            TRM4,TRM5,TRM6:   .19039-004     .00000          .00000

TIME =   .4600        RATE =   .66025+000       POSITION =   .27607+000
            TRM4,TRM5,TRM6:   .14954-004     .00000          .00000
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```
TIME =   .4700        RATE =   .66026+000        POSITION =   .25268+000
                TRM4,TRM5,TRM6:   .11745-004    .00000          .00000

TIME =   .4800        RATE =   .66026+000        POSITION =   .28928+000
                TRM4,TRM5,TRM6:   .92246-005    .00000          .00000

TIME =   .4900        RATE =   .66026+000        POSITION =   .29588+000
                TRM4,TRM5,TRM6:   .72454-005    .00000          .00000

TIME =   .5000        RATE =   .66026+000        POSITION =   .30248+000
                TRM4,TRM5,TRM6:   .56907-005    .00000          .00000

TIME =   .5100        RATE =   .66026+000        POSITION =   .30909+000
                TRM4,TRM5,TRM6:   .44696-005    .00000          .00000

TIME =   .5200        RATE =   .66026+000        POSITION =   .31569+000
                TRM4,TRM5,TRM6:   .35105-005    .00000          .00000

TIME =   .5300        RATE =   .66026+000        POSITION =   .32229+000
                TRM4,TRM5,TRM6:   .27572-005    .00000          .00000

TIME =   .5400        RATE =   .66026+000        POSITION =   .32889+000
                TRM4,TRM5,TRM6:   .21656-005    .00000          .00000

TIME =   .5500        RATE =   .66026+000        POSITION =   .33550+000
                TRM4,TRM5,TRM6:   .17009-005    .00000          .00000

TIME =   .5600        RATE =   .66026+000        POSITION =   .34210+000
                TRM4,TRM5,TRM6:   .13359-005    .00000          .00000

TIME =   .5700        RATE =   .66026+000        POSITION =   .34870+000
                TRM4,TRM5,TRM6:   .10493-005    .00000          .00000

TIME =   .5800        RATE =   .66026+000        POSITION =   .35530+000
                TRM4,TRM5,TRM6:   .82412-006    .00000          .00000

TIME =   .5900        RATE =   .66026+000        POSITION =   .36191+000
                TRM4,TRM5,TRM6:   .64728-006    .00000          .00000

TIME =   .6000        RATE =   .66026+000        POSITION =   .36851+000
                TRM4,TRM5,TRM6:   .50839-006    .00000          .00000

TIME =   .6100        RATE =   .66026+000        POSITION =   .37511+000
                TRM4,TRM5,TRM6:   .39930-006    .00000          .00000

TIME =   .6200        RATE =   .66026+000        POSITION =   .38171+000
                TRM4,TRM5,TRM6:   .31362-006    .00000          .00000

TIME =   .6300        RATE =   .66026+000        POSITION =   .38832+000
                TRM4,TRM5,TRM6:   .24632-006    .00000          .00000

TIME =   .6400        RATE =   .66026+000        POSITION =   .39492+000
                TRM4,TRM5,TRM6:   .19347-006    .00000          .00000

TIME =   .6500        RATE =   .66026+000        POSITION =   .40152+000
                TRM4,TRM5,TRM6:   .15195-006    .00000          .00000
```

```
TIME =   .6600         RATE =    .66026+000        POSITION =    .40813+000
                TRM4,TRM5,TRM6:    .11935-006       .00000           .00000

TIME =   .6700         RATE =    .66026+000        POSITION =    .41473+000
                TRM4,TRM5,TRM6:    .93759-007       .00000           .00000

TIME =   .6800         RATE =    .66026+000        POSITION =    .42133+000
                TRM4,TRM5,TRM6:    .73625-007       .00000           .00000

TIME =   .6900         RATE =    .66026+000        POSITION =    .42793+000
                TRM4,TRM5,TRM6:    .57827-007       .00000           .00000

TIME =   .7000         RATE =    .66026+000        POSITION =    .43454+000
                TRM4,TRM5,TRM6:    .45418-007       .00000           .00000

TIME =   .7100         RATE =    .66026+000        POSITION =    .44114+000
                TRM4,TRM5,TRM6:    .35673-007       .00000           .00000

TIME =   .7200         RATE =    .66026+000        POSITION =    .44774+000
                TRM4,TRM5,TRM6:    .28016-007       .00000           .00000

TIME =   .7300         RATE =    .66026+000        POSITION =    .45434+000
                TRM4,TRM5,TRM6:    .22006-007       .00000           .00000

TIME =   .7400         RATE =    .66026+000        POSITION =    .46095+000
                TRM4,TRM5,TRM6:    .17284-007       .00000           .00000

TIME =   .7500         RATE =    .66026+000        POSITION =    .46755+000
                TRM4,TRM5,TRM6:    .13575-007       .00000           .00000

TIME =   .7600         RATE =    .66026+000        POSITION =    .47415+000
                TRM4,TRM5,TRM6:    .10662-007       .00000           .00000

TIME =   .7700         RATE =    .66026+000        POSITION =    .48075+000
                TRM4,TRM5,TRM6:    .83744-008       .00000           .00000

TIME =   .7800         RATE =    .66026+000        POSITION =    .48736+000
                TRM4,TRM5,TRM6:    .65774-008       .00000           .00000

TIME =   .7900         RATE =    .66026+000        POSITION =    .49396+000
                TRM4,TRM5,TRM6:    .51661-008       .00000           .00000

TIME =   .8000         RATE =    .66026+000        POSITION =    .50056+000
                TRM4,TRM5,TRM6:    .40575-008       .00000           .00000

TIME =   .8100         RATE =    .66026+000        POSITION =    .50716+000
                TRM4,TRM5,TRM6:    .31869-008       .00000           .00000

TIME =   .8200         RATE =    .66026+000        POSITION =    .51377+000
                TRM4,TRM5,TRM6:    .25031-008       .00000           .00000

TIME =   .8300         RATE =    .66026+000        POSITION =    .52037+000
                TRM4,TRM5,TRM6:    .19660-008       .00000           .00000

TIME =   .8400         RATE =    .66026+000        POSITION =    .52697+000
                TRM4,TRM5,TRM6:    .15441-008       .00000           .00000
```

```
TIME =   .8500        RATE =    .66026+000        POSITION =   .53358+000
            TRM4,TRM5,TRM6:    .12126-008      .00000           .00000

TIME =   .8600        RATE =    .66026+000        POSITION =   .54018+000
            TRM4,TRM5,TRM6:    .95254-009      .00000           .00000

TIME =   .8700        RATE =    .66026+000        POSITION =   .54678+000
            TRM4,TRM5,TRM6:    .74615-009      .00000           .00000

TIME =   .8800        RATE =    .66026+000        POSITION =   .55338+000
            TRM4,TRM5,TRM6:    .58761-009      .00000           .00000

TIME =   .8900        RATE =    .66026+000        POSITION =   .55999+000
            TRM4,TRM5,TRM6:    .46152-009      .00000           .00000

TIME =   .9000        RATE =    .66026+000        POSITION =   .56659+000
            TRM4,TRM5,TRM6:    .36249-009      .00000           .00000

TIME =   .9100        RATE =    .66026+000        POSITION =   .57319+000
            TRM4,TRM5,TRM6:    .28471-009      .00000           .00000

TIME =   .9200        RATE =    .66026+000        POSITION =   .57979+000
            TRM4,TRM5,TRM6:    .22362-009      .00000           .00000

TIME =   .9300        RATE =    .66026+000        POSITION =   .58640+000
            TRM4,TRM5,TRM6:    .17563-009      .00000           .00000

TIME =   .9400        RATE =    .66026+000        POSITION =   .59300+000
            TRM4,TRM5,TRM6:    .13795-009      .00000           .00000

TIME =   .9500        RATE =    .66026+000        POSITION =   .59960+000
            TRM4,TRM5,TRM6:    .10835-009      .00000           .00000

TIME =   .9600        RATE =    .66026+000        POSITION =   .60620+000
            TRM4,TRM5,TRM6:    .85097-010      .00000           .00000

TIME =   .9700        RATE =    .66026+000        POSITION =   .61281+000
            TRM4,TRM5,TRM6:    .66837-010      .00000           .00000

TIME =   .9800        RATE =    .66026+000        POSITION =   .61941+000
            TRM4,TRM5,TRM6:    .52496-010      .00000           .00000

TIME =   .9900        RATE =    .66026+000        POSITION =   .62601+000
            TRM4,TRM5,TRM6:    .41231-010      .00000           .00000

TIME =  1.0000        RATE =    .66026+000        POSITION =   .63261+000
            TRM4,TRM5,TRM6:    .32384-010      .00000           .00000

STOP    9999

@PRT R.IUVLTDF
FURPUR 27R3A      E36 SL74R1 04/17/80 13:54:55
```

```
LADSS*AMLIN(1).IGVLID*
     1        A      *      1.0
     2        TAUA   *   .000001
     3        LA     *    .00276
     4        RA     *     9.317
     5        RSB    *       0.0
     6        KT     *     19.75
     7        K      *      12.8
     8        JP     *     .0015
     9        JL     *      2.47
    10        B      *      .622
    11        KE     *      .141
    12          100          .01    20

@XQT R.PROG
```

```
A            1.000
TAUA          .00000
LA            .00278
KA           5.31700
RSD           .00000
KT          15.75000
N           12.80000
JM            .00150
JL           2.47000
JT           2.71576
D             .62200
KE            .14100

 F, W, R:        .100335167167+007      .335172905600+010      .612000092160+011
 X,DX,BL:      -.162614098883+002      .180614098883+002      .605297035389+011
 B1,B2,C1,C2:      .335152838571+010      .100335147187+007      .335132771545+010      .100335127187+007
 X,DX,BL:      -.163601409377+002      .987310494145-001      .327301803587+009
 B1,B2,C1,C2:      .333340677334+010      .100333341047+007      .331508482415+010      .100331514906+007
 X,DX,BL:      -.163601438881+002      .295031398547-005      .977995662391+004
 B1,B2,C1,C2:      .333330771499+010      .100333331173+007      .331488671107+010      .100331495159+007
 X,DX,BL:      -.163601438881+002      .262521133035-014      .670227813721-005
 B1,B2,C1,C2:      .333330771203+010      .100333331173+007      .331488670515+010      .100331495159+007

 THREE REAL ROOTS

 RR1,RR2,RR3:    -.163601438881+002      -.333330769859+004      -.100000000403+007

 TT1,TT2,TT3:     .544658040861-001       .300002307145-003       .999999995967-006

 TRR1,TRR2,TRR3:     .541658017790-001       .544648040861-001       .299002307149-003

 GAIN =     .547128560860+000

TIME =    .0100        RATE =      .89241-001        POSITION =     .44603-003
             TRM4,TRM5,TRM6:    .83227+000        .33391-014       .00000

TIME =    .0200        RATE =      .16604+000        POSITION =     .17342-002
             TRM4,TRM5,TRM6:    .69267+000        .11150-028       .00000

TIME =    .0300        RATE =      .22996+000        POSITION =     .37240-002
             TRM4,TRM5,TRM6:    .57649+000        .37229-043       .00000

TIME =    .0400        RATE =      .28310+000        POSITION =     .62978-002
             TRM4,TRM5,TRM6:    .47979+000        .12431-057       .00000

TIME =    .0500        RATE =      .32744+000        POSITION =     .93575-002
             TRM4,TRM5,TRM6:    .39931+000        .41509-072       .00000

TIME =    .0600        RATE =      .36429+000        POSITION =     .12622-001
             TRM4,TRM5,TRM6:    .33234+000        .13860-086       .00000

TIME =    .0700        RATE =      .39496+000        POSITION =     .16623-001
             TRM4,TRM5,TRM6:    .27659+000        .46281-101       .00000

TIME =    .0800        RATE =      .42046+000        POSITION =     .20704-001
             TRM4,TRM5,TRM6:    .23020+000        .15454-115       .00000
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TIME =  .0900      RATE =    .44172+000      POSITION =   .25018-001
           TRM4,TRM5,TRM6:   .19159+000     .51601-130     .00000

TIME =  .1000      RATE =    .45940+000      POSITION =   .29526-001
           TRM4,TRM5,TRM6:   .15945+000     .17230-144     .00000

TIME =  .1100      RATE =    .47412+000      POSITION =   .34196-001
           TRM4,TRM5,TRM6:   .13271+000     .57533-159     .00000

TIME =  .1200      RATE =    .48630+000      POSITION =   .39001-001
           TRM4,TRM5,TRM6:   .11045+000     .19211-173     .00000

TIME =  .1300      RATE =    .49656+000      POSITION =   .43917-001
           TRM4,TRM5,TRM6:   .91922-001     .64147-188     .00000

TIME =  .1400      RATE =    .50504+000      POSITION =   .42926-001
           TRM4,TRM5,TRM6:   .76503-001     .21419-202     .00000

TIME =  .1500      RATE =    .51210+000      POSITION =   .54013-001
           TRM4,TRM5,TRM6:   .63671-001     .71521-217     .00000

TIME =  .1600      RATE =    .51797+000      POSITION =   .59164-001
           TRM4,TRM5,TRM6:   .52992-001     .23851-231     .00000

TIME =  .1700      RATE =    .52286+000      POSITION =   .64369-001
           TRM4,TRM5,TRM6:   .44103-001     .79742-246     .00000

TIME =  .1800      RATE =    .52695+000      POSITION =   .69619-001
           TRM4,TRM5,TRM6:   .36706-001     .26627-260     .00000

TIME =  .1900      RATE =    .53032+000      POSITION =   .74905-001
           TRM4,TRM5,TRM6:   .30549-001     .88909-275     .00000

TIME =  .2000      RATE =    .53314+000      POSITION =   .80223-001
           TRM4,TRM5,TRM6:   .25425-001     .29687-289     .00000

TIME =  .2100      RATE =    .53549+000      POSITION =   .85567-001
           TRM4,TRM5,TRM6:   .21160-001     .99129-304     .00000

TIME =  .2200      RATE =    .53744+000      POSITION =   .90932-001
           TRM4,TRM5,TRM6:   .17611-001     .00000         .00000

TIME =  .2300      RATE =    .53906+000      POSITION =   .96314-001
           TRM4,TRM5,TRM6:   .14657-001     .00000         .00000

TIME =  .2400      RATE =    .54042+000      POSITION =   .10171+000
           TRM4,TRM5,TRM6:   .12199-001     .00000         .00000

TIME =  .2500      RATE =    .54154+000      POSITION =   .10712+000
           TRM4,TRM5,TRM6:   .10152-001     .00000         .00000

TIME =  .2600      RATE =    .54243+000      POSITION =   .11254+000
           TRM4,TRM5,TRM6:   .84496-002     .00000         .00000

TIME =  .2700      RATE =    .54326+000      POSITION =   .11797+000
           TRM4,TRM5,TRM6:   .70323-002     .00000         .00000
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TIME =   .2800      RATE =   .54391+000      POSITION =   .12341+000
           TRM4,TRM5,TRM6:   .56526-002      .00000        .00000
TIME =   .2900      RATE =   .54445+000      POSITION =   .12885+000
           TRM4,TRM5,TRM6:   .48711-002      .00000        .00000
TIME =   .3000      RATE =   .54490+000      POSITION =   .13430+000
           TRM4,TRM5,TRM6:   .40540-002      .00000        .00000
TIME =   .3100      RATE =   .54527+000      POSITION =   .13975+000
           TRM4,TRM5,TRM6:   .33740-002      .00000        .00000
TIME =   .3200      RATE =   .54556+000      POSITION =   .14520+000
           TRM4,TRM5,TRM6:   .28081-002      .00000        .00000
TIME =   .3300      RATE =   .54584+000      POSITION =   .15066+000
           TRM4,TRM5,TRM6:   .23371-002      .00000        .00000
TIME =   .3400      RATE =   .54606+000      POSITION =   .15612+000
           TRM4,TRM5,TRM6:   .19451-002      .00000        .00000
TIME =   .3500      RATE =   .54624+000      POSITION =   .16158+000
           TRM4,TRM5,TRM6:   .16188-002      .00000        .00000
TIME =   .3600      RATE =   .54639+000      POSITION =   .16704+000
           TRM4,TRM5,TRM6:   .13473-002      .00000        .00000
TIME =   .3700      RATE =   .54651+000      POSITION =   .17251+000
           TRM4,TRM5,TRM6:   .11213-002      .00000        .00000
TIME =   .3800      RATE =   .54662+000      POSITION =   .17797+000
           TRM4,TRM5,TRM6:   .93323-003      .00000        .00000
TIME =   .3900      RATE =   .54670+000      POSITION =   .18344+000
           TRM4,TRM5,TRM6:   .77670-003      .00000        .00000
TIME =   .4000      RATE =   .54677+000      POSITION =   .18891+000
           TRM4,TRM5,TRM6:   .64642-003      .00000        .00000
TIME =   .4100      RATE =   .54683+000      POSITION =   .19437+000
           TRM4,TRM5,TRM6:   .53800-003      .00000        .00000
TIME =   .4200      RATE =   .54688+000      POSITION =   .19984+000
           TRM4,TRM5,TRM6:   .44776-003      .00000        .00000
TIME =   .4300      RATE =   .54692+000      POSITION =   .20531+000
           TRM4,TRM5,TRM6:   .37265-003      .00000        .00000
TIME =   .4400      RATE =   .54696+000      POSITION =   .21078+000
           TRM4,TRM5,TRM6:   .31015-003      .00000        .00000
TIME =   .4500      RATE =   .54699+000      POSITION =   .21625+000
           TRM4,TRM5,TRM6:   .25813-003      .00000        .00000
TIME =   .4600      RATE =   .54701+000      POSITION =   .22172+000
           TRM4,TRM5,TRM6:   .21483-003      .00000        .00000
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TIME =   .4700          RATE =   .54703+000          POSITION =   .22719+000
                  TRM4,TRM5,TRM6:   .17660-003       .00000           .00000

TIME =   .4800          RATE =   .54705+000          POSITION =   .23266+000
                  TRM4,TRM5,TRM6:   .14661-003       .00000           .00000

TIME =   .4900          RATE =   .54706+000          POSITION =   .23813+000
                  TRM4,TRM5,TRM6:   .12385-003       .00000           .00000

TIME =   .5000          RATE =   .54707+000          POSITION =   .24360+000
                  TRM4,TRM5,TRM6:   .10307-003       .00000           .00000

TIME =   .5100          RATE =   .54708+000          POSITION =   .24907+000
                  TRM4,TRM5,TRM6:   .85764-004       .00000           .00000

TIME =   .5200          RATE =   .54709+000          POSITION =   .25454+000
                  TRM4,TRM5,TRM6:   .71396-004       .00000           .00000

TIME =   .5300          RATE =   .54710+000          POSITION =   .26002+000
                  TRM4,TRM5,TRM6:   .59420-004       .00000           .00000

TIME =   .5400          RATE =   .54710+000          POSITION =   .26549+000
                  TRM4,TRM5,TRM6:   .49454-004       .00000           .00000

TIME =   .5500          RATE =   .54711+000          POSITION =   .27096+000
                  TRM4,TRM5,TRM6:   .41159-004       .00000           .00000

TIME =   .5600          RATE =   .54711+000          POSITION =   .27643+000
                  TRM4,TRM5,TRM6:   .34255-004       .00000           .00000

TIME =   .5700          RATE =   .54711+000          POSITION =   .28190+000
                  TRM4,TRM5,TRM6:   .28509-004       .00000           .00000

TIME =   .5800          RATE =   .54712+000          POSITION =   .28737+000
                  TRM4,TRM5,TRM6:   .23727-004       .00000           .00000

TIME =   .5900          RATE =   .54712+000          POSITION =   .29284+000
                  TRM4,TRM5,TRM6:   .19747-004       .00000           .00000

TIME =   .6000          RATE =   .54712+000          POSITION =   .29831+000
                  TRM4,TRM5,TRM6:   .16435-004       .00000           .00000

TIME =   .6100          RATE =   .54712+000          POSITION =   .30378+000
                  TRM4,TRM5,TRM6:   .13678-004       .00000           .00000

TIME =   .6200          RATE =   .54712+000          POSITION =   .30926+000
                  TRM4,TRM5,TRM6:   .11384-004       .00000           .00000

TIME =   .6300          RATE =   .54712+000          POSITION =   .31473+000
                  TRM4,TRM5,TRM6:   .94747-005       .00000           .00000

TIME =   .6400          RATE =   .54712+000          POSITION =   .32020+000
                  TRM4,TRM5,TRM6:   .78854-005       .00000           .00000

TIME =   .6500          RATE =   .54712+000          POSITION =   .32567+000
                  TRM4,TRM5,TRM6:   .65628-005       .00000           .00000
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TIME =   .6600      RATE =   .54713+000      POSITION =   .33114+000
           TRM4,TRM5,TRM6:   .54626-005     .00000         .00000

TIME =   .6700      RATE =   .54713+000      POSITION =   .33661+000
           TRM4,TRM5,TRM6:   .45458-005     .00000         .00000

TIME =   .6800      RATE =   .54713+000      POSITION =   .34208+000
           TRM4,TRM5,TRM6:   .37834-005     .00000         .00000

TIME =   .6900      RATE =   .54713+000      POSITION =   .34755+000
           TRM4,TRM5,TRM6:   .31488-005     .00000         .00000

TIME =   .7000      RATE =   .54713+000      POSITION =   .35303+000
           TRM4,TRM5,TRM6:   .26206-005     .00000         .00000

TIME =   .7100      RATE =   .54713+000      POSITION =   .35850+000
           TRM4,TRM5,TRM6:   .21811-005     .00000         .00000

TIME =   .7200      RATE =   .54713+000      POSITION =   .36397+000
           TRM4,TRM5,TRM6:   .18152-005     .00000         .00000

TIME =   .7300      RATE =   .54713+000      POSITION =   .36944+000
           TRM4,TRM5,TRM6:   .15107-005     .00000         .00000

TIME =   .7400      RATE =   .54713+000      POSITION =   .37491+000
           TRM4,TRM5,TRM6:   .12573-005     .00000         .00000

TIME =   .7500      RATE =   .54713+000      POSITION =   .38038+000
           TRM4,TRM5,TRM6:   .10464-005     .00000         .00000

TIME =   .7600      RATE =   .54713+000      POSITION =   .38585+000
           TRM4,TRM5,TRM6:   .87093-006     .00000         .00000

TIME =   .7700      RATE =   .54713+000      POSITION =   .39132+000
           TRM4,TRM5,TRM6:   .72484-006     .00000         .00000

TIME =   .7800      RATE =   .54713+000      POSITION =   .39680+000
           TRM4,TRM5,TRM6:   .60326-006     .00000         .00000

TIME =   .7900      RATE =   .54713+000      POSITION =   .40227+000
           TRM4,TRM5,TRM6:   .50208-006     .00000         .00000

TIME =   .8000      RATE =   .54713+000      POSITION =   .40774+000
           TRM4,TRM5,TRM6:   .41786-006     .00000         .00000

TIME =   .8100      RATE =   .54713+000      POSITION =   .41321+000
           TRM4,TRM5,TRM6:   .34777-006     .00000         .00000

TIME =   .8200      RATE =   .54713+000      POSITION =   .41868+000
           TRM4,TRM5,TRM6:   .28944-006     .00000         .00000

TIME =   .8300      RATE =   .54713+000      POSITION =   .42415+000
           TRM4,TRM5,TRM6:   .24089-006     .00000         .00000

TIME =   .8400      RATE =   .54713+000      POSITION =   .42962+000
           TRM4,TRM5,TRM6:   .20049-006     .00000         .00000
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TIME =   .8500        RATE =    .54713+000        POSITION =    .43509+000
              TRM4,TRM5,TRM6:    .16636-006       .00000          .00000

TIME =   .8600        RATE =    .54713+000        POSITION =    .44057+000
              TRM4,TRM5,TRM6:    .13687-006       .00000          .00000

TIME =   .8700        RATE =    .54713+000        POSITION =    .44604+000
              TRM4,TRM5,TRM6:    .11558-006       .00000          .00000

TIME =   .8800        RATE =    .54713+000        POSITION =    .45151+000
              TRM4,TRM5,TRM6:    .96191-007       .00000          .00000

TIME =   .8900        RATE =    .54713+000        POSITION =    .45698+000
              TRM4,TRM5,TRM6:    .80057-007       .00000          .00000

TIME =   .9000        RATE =    .54713+000        POSITION =    .46245+000
              TRM4,TRM5,TRM6:    .66629-007       .00000          .00000

TIME =   .9100        RATE =    .54713+000        POSITION =    .46792+000
              TRM4,TRM5,TRM6:    .55453-007       .00000          .00000

TIME =   .9200        RATE =    .54713+000        POSITION =    .47339+000
              TRM4,TRM5,TRM6:    .46152-007       .00000          .00000

TIME =   .9300        RATE =    .54713+000        POSITION =    .47887+000
              TRM4,TRM5,TRM6:    .38411-007       .00000          .00000

TIME =   .9400        RATE =    .54713+000        POSITION =    .48434+000
              TRM4,TRM5,TRM6:    .31966-007       .00000          .00000

TIME =   .9500        RATE =    .54713+000        POSITION =    .48981+000
              TRM4,TRM5,TRM6:    .26606-007       .00000          .00000

TIME =   .9600        RATE =    .54713+000        POSITION =    .49528+000
              TRM4,TRM5,TRM6:    .22143-007       .00000          .00000

TIME =   .9700        RATE =    .54713+000        POSITION =    .50075+000
              TRM4,TRM5,TRM6:    .18429-007       .00000          .00000

TIME =   .9800        RATE =    .54713+000        POSITION =    .50622+000
              TRM4,TRM5,TRM6:    .15338-007       .00000          .00000

TIME =   .9900        RATE =    .54713+000        POSITION =    .51169+000
              TRM4,TRM5,TRM6:    .12765-007       .00000          .00000

TIME =  1.0000        RATE =    .54713+000        POSITION =    .51716+000
              TRM4,TRM5,TRM6:    .10624-007       .00000          .00000

STOP    5999

.PRT R.OGCNIDR
FURPUR 27R3A      E36 SL74R1 04/17/80 13:54:59
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LADSS*AMLIR(1).OGCNTD*
     1        A       *   100000.0
     2        T/UA    *        .02
     3        LA      *      .0014
     4        RA      *        3.0
     5        RSG     *        1.0
     6        KT      *       24.8
     7        N       *        6.5
     8        JY      *       .016
     9        JL      *       3.30
    10        D       *       .706
    11        KE      *       .177
    12          100           .01   .0

*XQT R.PROG
```

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A        100000.000
TAUA         .0.000
LA           .00140
RA          1.00000
RSB         1.00000
KT         24.80000
N           6.50000
JM           .01600
JL          1.30000
JT          4.45600
D            .70600
KE           .17750

  T, Q, R:      .219301556396+004       .357158688000+010       .568409096000+009
 X,DX,BC:    -.159147506971+000      -.408524930292-001      -.145908192287+009
 B1,B2,C1,C2:      .357158644144+010       .219261556396+004       .357158600291+010       .219261556396+004
 X,DX,BC:    -.159147507995+000       .102448820757-008       .365904792584+001
 B1,B2,C1,C2:      .357158653101+010       .219285641646+004       .357158618205+010       .219269726895+004
 X,DX,BC:    -.159147507995+000       .260758813352-018       .931322574615-009
 B1,B2,C1,C2:      .357158653101+010       .219285641646+004       .357158618205+010       .219269726895+004

  ONE REAL ROOT, TWO COMPLEX ROOTS

  PR, ALPHA, BETA:   -.159147507995+000    -.109642820823+004     .597526934639+005

  TT:     .628347884674+001

  OMEGA, TRM1, TRM2, TRM3:        .597627520368+005       .141013745719+012       .375517969901+006      -.545055001595+002

  GAIN =     .297239397538+003          ZETA =     .183463473629-001

  NUM =    100      TINC =     .01000      STOPT =     1.00000

  ITER =    20

  THIR =   -.310490036270+001     PHIP =   -.465734951278+001

 TIME =    .0100          RATE =    .47264+000          POSITION =    .23637-002
            TRM4,TRM5,TRM6:     .99841+000       .17309-004       .59753+003

 TIME =    .0200          RATE =    .94457+000          POSITION =    .94504-002
            TRM4,TRM5,TRM6:     .99682+000       .29960-009       .11951+004

 TIME =    .0300          RATE =    .14157+001          POSITION =    .21252-001
            TRM4,TRM5,TRM6:     .99524+000       .51858-014       .17926+004

 TIME =    .0400          RATE =    .18662+001          POSITION =    .37763-001
            TRM4,TRM5,TRM6:     .99365+000       .89762-019       .23901+004

 TIME =    .0500          RATE =    .23550+001          POSITION =    .58973-001
            TRM4,TRM5,TRM6:     .99207+000       .15537-023       .29876+004

 TIME =    .0600          RATE =    .28246+001          POSITION =    .84877-001
            TRM4,TRM5,TRM6:     .99050+000       .26893-028       .35852+004

 TIME =    .0700          RATE =    .32929+001          POSITION =    .11547+000
            TRM4,TRM5,TRM6:     .98892+000       .46549-033       .41827+004
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TIME =   .0800        RATE =    .37604+001        POSITION =   .15073+000
                 TRM4,TRM5,TRM6:   .98735+000     .80572-058     .47802+004

TIME =   .0900        RATE =    .42271+001        POSITION =   .15067+000
                 TRM4,TRM5,TRM6:   .98578+000     .13946-042     .53777+004

TIME =   .1000        RATE =    .46930+001        POSITION =   .23527+000
                 TRM4,TRM5,TRM6:   .98421+000     .24139-047     .59753+004

TIME =   .1100        RATE =    .51582+001        POSITION =   .28453+000
                 TRM4,TRM5,TRM6:   .98265+000     .41763-052     .65728+004

TIME =   .1200        RATE =    .56227+001        POSITION =   .33843+000
                 TRM4,TRM5,TRM6:   .98108+000     .72323-057     .71703+004

TIME =   .1300        RATE =    .60864+001        POSITION =   .39698+000
                 TRM4,TRM5,TRM6:   .97952+000     .12518-061     .77679+004

TIME =   .1400        RATE =    .65494+001        POSITION =   .46016+000
                 TRM4,TRM5,TRM6:   .97797+000     .21668-066     .83654+004

TIME =   .1500        RATE =    .70117+001        POSITION =   .52797+000
                 TRM4,TRM5,TRM6:   .97641+000     .37505-071     .89629+004

TIME =   .1600        RATE =    .74732+001        POSITION =   .60039+000
                 TRM4,TRM5,TRM6:   .97486+000     .64918-076     .95604+004

TIME =   .1700        RATE =    .79340+001        POSITION =   .67743+000
                 TRM4,TRM5,TRM6:   .97331+000     .11237-080     .10158+005

TIME =   .1800        RATE =    .83941+001        POSITION =   .75907+000
                 TRM4,TRM5,TRM6:   .97176+000     .19450-085     .10755+005

TIME =   .1900        RATE =    .88534+001        POSITION =   .84531+000
                 TRM4,TRM5,TRM6:   .97021+000     .33665-090     .11353+005

TIME =   .2000        RATE =    .93120+001        POSITION =   .93613+000
                 TRM4,TRM5,TRM6:   .96867+000     .58272-095     .11951+005

TIME =   .2100        RATE =    .97698+001        POSITION =   .10315+001
                 TRM4,TRM5,TRM6:   .96713+000     .10086-099     .12548+005

TIME =   .2200        RATE =    .10227+002        POSITION =   .11315+001
                 TRM4,TRM5,TRM6:   .96559+000     .17458-104     .13146+005

TIME =   .2300        RATE =    .10683+002        POSITION =   .12361+001
                 TRM4,TRM5,TRM6:   .96406+000     .30219-109     .13743+005

TIME =   .2400        RATE =    .11139+002        POSITION =   .13452+001
                 TRM4,TRM5,TRM6:   .96252+000     .52305-114     .14341+005

TIME =   .2500        RATE =    .11594+002        POSITION =   .14589+001
                 TRM4,TRM5,TRM6:   .96099+000     .90536-119     .14938+005

TIME =   .2600        RATE =    .12048+002        POSITION =   .15771+001
                 TRM4,TRM5,TRM6:   .95947+000     .15671-123     .15536+005
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TIME =   .2700        RATE =   .12502+002        POSITION =   .16998+001
                TRM4,TRM5,TRM6:   .95794+000     .27125-128     .16135+005

TIME =   .2800        RATE =   .12955+002        POSITION =   .18271+001
                TRM4,TRM5,TRM6:   .95642+000     .46950-133     .16731+005

TIME =   .2900        RATE =   .13407+002        POSITION =   .19589+001
                TRM4,TRM5,TRM6:   .95490+000     .51266-138     .17328+005

TIME =   .3000        RATE =   .13858+002        POSITION =   .20952+001
                TRM4,TRM5,TRM6:   .95338+000     .14066-142     .17926+005

TIME =   .3100        RATE =   .14309+002        POSITION =   .22361+001
                TRM4,TRM5,TRM6:   .95186+000     .24348-147     .18523+005

TIME =   .3200        RATE =   .14759+002        POSITION =   .23814+001
                TRM4,TRM5,TRM6:   .95035+000     .42143-152     .19121+005

TIME =   .3300        RATE =   .15206+002        POSITION =   .25312+001
                TRM4,TRM5,TRM6:   .94884+000     .72946-157     .19718+005

TIME =   .3400        RATE =   .15656+002        POSITION =   .26856+001
                TRM4,TRM5,TRM6:   .94733+000     .12626-161     .20316+005

TIME =   .3500        RATE =   .16104+002        POSITION =   .28444+001
                TRM4,TRM5,TRM6:   .94582+000     .21855-166     .20913+005

TIME =   .3600        RATE =   .16551+002        POSITION =   .30076+001
                TRM4,TRM5,TRM6:   .94432+000     .37829-171     .21511+005

TIME =   .3700        RATE =   .16997+002        POSITION =   .31754+001
                TRM4,TRM5,TRM6:   .94282+000     .65478-176     .22108+005

TIME =   .3800        RATE =   .17443+002        POSITION =   .33476+001
                TRM4,TRM5,TRM6:   .94132+000     .11334-180     .22706+005

TIME =   .3900        RATE =   .17888+002        POSITION =   .35242+001
                TRM4,TRM5,TRM6:   .93982+000     .19617-185     .23304+005

TIME =   .4000        RATE =   .18332+002        POSITION =   .37053+001
                TRM4,TRM5,TRM6:   .93832+000     .33956-190     .23901+005

TIME =   .4100        RATE =   .18776+002        POSITION =   .38909+001
                TRM4,TRM5,TRM6:   .93683+000     .58774-195     .24499+005

TIME =   .4200        RATE =   .19219+002        POSITION =   .40809+001
                TRM4,TRM5,TRM6:   .93534+000     .10173-199     .25096+005

TIME =   .4300        RATE =   .19661+002        POSITION =   .42752+001
                TRM4,TRM5,TRM6:   .93386+000     .17609-204     .25694+005

TIME =   .4400        RATE =   .20102+002        POSITION =   .44741+001
                TRM4,TRM5,TRM6:   .93237+000     .30479-209     .26291+005

TIME =   .4500        RATE =   .20543+002        POSITION =   .46773+001
                TRM4,TRM5,TRM6:   .93069+000     .52757-214     .26889+005
```

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TIME =    .4600        RATE =    .20983+002         POSITION =    .48849+001
              TRM4,TRM5,TRM6:     .92941+000      .91317-219      .27486+005

TIME =    .4700        RATE =    .21422+002         POSITION =    .50969+001
              TRM4,TRM5,TRM6:     .92793+000      .15806-223      .28084+005

TIME =    .4800        RATE =    .21861+002         POSITION =    .53134+001
              TRM4,TRM5,TRM6:     .92645+000      .27359-228      .28681+005

TIME =    .4900        RATE =    .22299+002         POSITION =    .55342+001
              TRM4,TRM5,TRM6:     .92498+000      .47355-233      .29279+005

TIME =    .5000        RATE =    .22736+002         POSITION =    .57593+001
              TRM4,TRM5,TRM6:     .92351+000      .81967-238      .29876+005

TIME =    .5100        RATE =    .23172+002         POSITION =    .59889+001
              TRM4,TRM5,TRM6:     .92204+000      .14188-242      .30474+005

TIME =    .5200        RATE =    .23608+002         POSITION =    .62228+001
              TRM4,TRM5,TRM6:     .92058+000      .24558-247      .31071+005

TIME =    .5300        RATE =    .24043+002         POSITION =    .64610+001
              TRM4,TRM5,TRM6:     .91911+000      .42507-252      .31669+005

TIME =    .5400        RATE =    .24478+002         POSITION =    .67036+001
              TRM4,TRM5,TRM6:     .91765+000      .73575-257      .32266+005

TIME =    .5500        RATE =    .24912+002         POSITION =    .69506+001
              TRM4,TRM5,TRM6:     .91619+000      .12735-261      .32864+005

TIME =    .5600        RATE =    .25345+002         POSITION =    .72019+001
              TRM4,TRM5,TRM6:     .91473+000      .22043-266      .33462+005

TIME =    .5700        RATE =    .25777+002         POSITION =    .74575+001
              TRM4,TRM5,TRM6:     .91328+000      .38155-271      .34059+005

TIME =    .5800        RATE =    .26209+002         POSITION =    .77174+001
              TRM4,TRM5,TRM6:     .91183+000      .66042-276      .34657+005

TIME =    .5900        RATE =    .26640+002         POSITION =    .79816+001
              TRM4,TRM5,TRM6:     .91038+000      .11431-280      .35254+005

TIME =    .6000        RATE =    .27070+002         POSITION =    .82502+001
              TRM4,TRM5,TRM6:     .90893+000      .19787-285      .35852+005

TIME =    .6100        RATE =    .27500+002         POSITION =    .85230+001
              TRM4,TRM5,TRM6:     .90748+000      .34248-290      .36449+005

TIME =    .6200        RATE =    .27928+002         POSITION =    .88002+001
              TRM4,TRM5,TRM6:     .90604+000      .59281-295      .37047+005

TIME =    .6300        RATE =    .28357+002         POSITION =    .90816+001
              TRM4,TRM5,TRM6:     .90460+000      .10261-299      .37644+005

TIME =    .6400        RATE =    .28784+002         POSITION =    .93673+001
              TRM4,TRM5,TRM6:     .90316+000      .17761-304      .38242+005
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TIME =   .6500        RATE =      .29211+002        POSITION =    .96573+001
                 TRM4,TRM5,TRM6:   .90172+000       .00000          .38839+005

TIME =   .6600        RATE =      .29637+002        POSITION =    .99515+001
                 TRM4,TRM5,TRM6:   .90029+000       .00000          .39437+005

TIME =   .6700        RATE =      .30063+002        POSITION =    .10250+002
                 TRM4,TRM5,TRM6:   .89886+000       .00000          .40034+005

TIME =   .6800        RATE =      .30488+002        POSITION =    .10553+002
                 TRM4,TRM5,TRM6:   .89743+000       .00000          .40632+005

TIME =   .6900        RATE =      .30912+002        POSITION =    .10860+002
                 TRM4,TRM5,TRM6:   .89600+000       .00000          .41229+005

TIME =   .7000        RATE =      .31336+002        POSITION =    .11171+002
                 TRM4,TRM5,TRM6:   .89458+000       .00000          .41827+005

TIME =   .7100        RATE =      .31758+002        POSITION =    .11487+002
                 TRM4,TRM5,TRM6:   .89316+000       .00000          .42424+005

TIME =   .7200        RATE =      .32181+002        POSITION =    .11806+002
                 TRM4,TRM5,TRM6:   .89174+000       .00000          .43022+005

TIME =   .7300        RATE =      .32602+002        POSITION =    .12130+002
                 TRM4,TRM5,TRM6:   .89032+000       .00000          .43619+005

TIME =   .7400        RATE =      .33023+002        POSITION =    .12458+002
                 TRM4,TRM5,TRM6:   .88890+000       .00000          .44217+005

TIME =   .7500        RATE =      .33443+002        POSITION =    .12791+002
                 TRM4,TRM5,TRM6:   .88749+000       .00000          .44815+005

TIME =   .7600        RATE =      .33863+002        POSITION =    .13127+002
                 TRM4,TRM5,TRM6:   .88608+000       .00000          .45412+005

TIME =   .7700        RATE =      .34281+002        POSITION =    .13468+002
                 TRM4,TRM5,TRM6:   .88467+000       .00000          .46010+005

TIME =   .7800        RATE =      .34700+002        POSITION =    .13813+002
                 TRM4,TRM5,TRM6:   .88326+000       .00000          .46607+005

TIME =   .7900        RATE =      .35117+002        POSITION =    .14162+002
                 TRM4,TRM5,TRM6:   .88186+000       .00000          .47205+005

TIME =   .8000        RATE =      .35534+002        POSITION =    .14515+002
                 TRM4,TRM5,TRM6:   .88045+000       .00000          .47802+005

TIME =   .8100        RATE =      .35950+002        POSITION =    .14872+002
                 TRM4,TRM5,TRM6:   .87905+000       .00000          .48400+005

TIME =   .8200        RATE =      .36366+002        POSITION =    .15234+002
                 TRM4,TRM5,TRM6:   .87766+000       .00000          .48997+005

TIME =   .8300        RATE =      .36780+002        POSITION =    .15600+002
                 TRM4,TRM5,TRM6:   .87626+000       .00000          .49595+005
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TIME =   .8400        RATE =   .37195+002        POSITION =    .15970+002
          TRM4,TRM5,TRM6:   .37467+000        .00000          .50192+005

TIME =   .8500        RATE =   .37608+002        POSITION =    .16344+002
          TRM4,TRM5,TRM6:   .87546+000        .00000          .50790+005

TIME =   .8600        RATE =   .38021+002        POSITION =    .16722+002
          TRM4,TRM5,TRM6:   .87209+000        .00000          .51387+005

TIME =   .8700        RATE =   .38433+002        POSITION =    .17104+002
          TRM4,TRM5,TRM6:   .87070+000        .00000          .51985+005

TIME =   .8800        RATE =   .38845+002        POSITION =    .17490+002
          TRM4,TRM5,TRM6:   .86931+000        .00000          .52582+005

TIME =   .8900        RATE =   .39256+002        POSITION =    .17881+002
          TRM4,TRM5,TRM6:   .86793+000        .00000          .53180+005

TIME =   .9000        RATE =   .39666+002        POSITION =    .18276+002
          TRM4,TRM5,TRM6:   .86655+000        .00000          .53777+005

TIME =   .9100        RATE =   .40075+002        POSITION =    .18674+002
          TRM4,TRM5,TRM6:   .86517+000        .00000          .54375+005

TIME =   .9200        RATE =   .40484+002        POSITION =    .19077+002
          TRM4,TRM5,TRM6:   .86380+000        .00000          .54972+005

TIME =   .9300        RATE =   .40893+002        POSITION =    .19484+002
          TRM4,TRM5,TRM6:   .86242+000        .00000          .55570+005

TIME =   .9400        RATE =   .41300+002        POSITION =    .19895+002
          TRM4,TRM5,TRM6:   .86105+000        .00000          .56168+005

TIME =   .9500        RATE =   .41707+002        POSITION =    .20310+002
          TRM4,TRM5,TRM6:   .85968+000        .00000          .56765+005

TIME =   .9600        RATE =   .42114+002        POSITION =    .20729+002
          TRM4,TRM5,TRM6:   .85832+000        .00000          .57363+005

TIME =   .9700        RATE =   .42519+002        POSITION =    .21152+002
          TRM4,TRM5,TRM6:   .85695+000        .00000          .57960+005

TIME =   .9800        RATE =   .42924+002        POSITION =    .21579+002
          TRM4,TRM5,TRM6:   .85559+000        .00000          .58558+005

TIME =   .9900        RATE =   .43329+002        POSITION =    .22011+002
          TRM4,TRM5,TRM6:   .85423+000        .00000          .59155+005

TIME =  1.0000        RATE =   .43733+002        POSITION =    .22446+002
          TRM4,TRM5,TRM6:   .85287+000        .00000          .59753+005

STOP    5999

@PRT R.ILCNTDR
FURPUR 27R3A     E36 SL74R1 04/17/80 13:55:03
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LADSS*AMLIK(1).IGCNTDR
     1        A     *   100000.0
     2        TAUA  *        .02
     3        LA    *     .00276
     4        HA    *      9.317
     5        RSU   *        1.0
     6        KT    *      19.75
     7        N     *       12.6
     8        JP    *      .0015
     9        JL    *       2.47
    10        D     *       .622
    11        KE    *       .141
    12         100           .01    ,0

@XQT R.PROG
```

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A       100000.000
TAUA        .01000
LA          .00278
KA         5.31700
RSB        1.00000
KT        15.75000
N         12.80000
JM          .00150
JL         2.47000
JT         2.71576
D           .62200
KE          .14100

  F, G, H:    .340166784668+004      .179876990400+010       .414990744000+009
 X,DX,BC:   -.230705609673+000      .307056096727-001       .552328992587+002
 B1,B2,C1,C2:    .179876922371+010      .340146784668+004       .179878854345+010       .340126784668+004
 X,DX,BC:   -.230705611655+000      .172652808641-008       .320661507640+001
 B1,B2,C1,C2:    .179878911927+010      .340143714107+004       .179878833459+010       .340120643546+004
 X,DX,BC:   -.230705611655+000      .000000000000          .000000000000
 B1,B2,C1,C2:    .179878911927+010      .340143714107+004       .179878833459+010       .340120643546+004

  ONE REAL ROOT, TWO COMPLEX ROOTS

  RR, ALPHA, BETA:   -.230705611655+000     -.170071857053+004      .423780211385+005

  TT:    .433452828835+001

  OMEGA, TRM1, TRM2, TRM3:     .424121341042+005      .337956789346+011      .183836554946+006     -.249210958862+002

  GAIN -     .403455904261+003          ZETA =    .400998112087-001

 NUP =   100      TINC =      .01000      STOPT =      1.00000

  ITER =     20

  PHIR =    -.305137695741+001      PHIP =   -.459206271850+001

TIME =    .0100         RATE =    .52950+000        POSITION =    .46483-002
                 TRM4,TRM5,TRM6:    .99770+000      .41703-007      .42378+003

TIME =    .0200         RATE =    .18570+001        POSITION =    .18583-001
                 TRM4,TRM5,TRM6:    .99540+000      .16895-014      .84756+003

TIME =    .0300         RATE =    .27824+001        POSITION =    .41782-001
                 TRM4,TRM5,TRM6:    .99310+000      .69442-022      .12713+004

TIME =    .0400         RATE =    .37057+001        POSITION =    .74224-001
                 TRM4,TRM5,TRM6:    .99081+000      .28543-029      .16951+004

TIME =    .0500         RATE =    .46266+001        POSITION =    .11589+000
                 TRM4,TRM5,TRM6:    .98853+000      .11732-036      .21189+004

TIME =    .0600         RATE =    .55458+001        POSITION =    .16675+000
                 TRM4,TRM5,TRM6:    .98625+000      .48221-044      .25427+004

TIME =    .0700         RATE =    .64627+001        POSITION =    .22680+000
                 TRM4,TRM5,TRM6:    .98398+000      .19820-051      .29665+004
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TIME =   .0800        RATE =   .73775+001       POSITION =   .27600+000
              TRM4,TRM5,TRM6:    .92171+000     .11468-059      .35902+004

TIME =   .0900        RATE =   .82902+001       POSITION =   .37434+000
              TRM4,TRM5,TRM6:    .97945+000     .33466-066      .36140+004

TIME =   .1000        RATE =   .92007+001       POSITION =   .46160+000
              TRM4,TRM5,TRM6:    .97719+000     .13764-073      .42376+004

TIME =   .1100        RATE =   .10109+002       POSITION =   .55835+000
              TRM4,TRM5,TRM6:    .97494+000     .56572-081      .46616+004

TIME =   .1200        RATE =   .11016+002       POSITION =   .66397+000
              TRM4,TRM5,TRM6:    .97270+000     .23253-088      .50854+004

TIME =   .1300        RATE =   .11920+002       POSITION =   .77865+000
              TRM4,TRM5,TRM6:    .97045+000     .95576-096      .55091+004

TIME =   .1400        RATE =   .12822+002       POSITION =   .90236+000
              TRM4,TRM5,TRM6:    .96822+000     .39285-103      .59329+004

TIME =   .1500        RATE =   .13722+002       POSITION =   .10351+001
              TRM4,TRM5,TRM6:    .96599+000     .16147-110      .63567+004

TIME =   .1600        RATE =   .14620+002       POSITION =   .11768+001
              TRM4,TRM5,TRM6:    .96376+000     .66370-118      .67805+004

TIME =   .1700        RATE =   .15516+002       POSITION =   .13275+001
              TRM4,TRM5,TRM6:    .96154+000     .27280-125      .72043+004

TIME =   .1800        RATE =   .16410+002       POSITION =   .14871+001
              TRM4,TRM5,TRM6:    .95932+000     .11213-132      .76280+004

TIME =   .1900        RATE =   .17302+002       POSITION =   .16557+001
              TRM4,TRM5,TRM6:    .95711+000     .46088-140      .80518+004

TIME =   .2000        RATE =   .18192+002       POSITION =   .18332+001
              TRM4,TRM5,TRM6:    .95491+000     .18944-147      .84756+004

TIME =   .2100        RATE =   .19080+002       POSITION =   .20195+001
              TRM4,TRM5,TRM6:    .95271+000     .77864-155      .88994+004

TIME =   .2200        RATE =   .19965+002       POSITION =   .22147+001
              TRM4,TRM5,TRM6:    .95051+000     .32004-162      .93232+004

TIME =   .2300        RATE =   .20849+002       POSITION =   .24188+001
              TRM4,TRM5,TRM6:    .94832+000     .13155-169      .97469+004

TIME =   .2400        RATE =   .21731+002       POSITION =   .26317+001
              TRM4,TRM5,TRM6:    .94614+000     .54070-177      .10171+005

TIME =   .2500        RATE =   .22610+002       POSITION =   .28534+001
              TRM4,TRM5,TRM6:    .94396+000     .22224-184      .10595+005

TIME =   .2600        RATE =   .23488+002       POSITION =   .30839+001
              TRM4,TRM5,TRM6:    .94178+000     .91349-192      .11018+005
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TIME =   .2700        RATE =      .24365+002         POSITION =   .33232+001
               TRM4,TRM5,TRM6:    .93961+000     .37547-199       .11442+005

TIME =   .2800        RATE =      .25237+002         POSITION =   .35712+001
               TRM4,TRM5,TRM6:    .93744+000     .15433-206       .11866+005

TIME =   .2900        RATE =      .26106+002         POSITION =   .38279+001
               TRM4,TRM5,TRM6:    .93528+000     .63434-214       .12290+005

TIME =   .3000        RATE =      .26976+002         POSITION =   .40953+001
               TRM4,TRM5,TRM6:    .93313+000     .26073-221       .12713+005

TIME =   .3100        RATE =      .27845+002         POSITION =   .43674+001
               TRM4,TRM5,TRM6:    .93098+000     .10717-228       .13137+005

TIME =   .3200        RATE =      .28711+002         POSITION =   .46502+001
               TRM4,TRM5,TRM6:    .92883+000     .44049-236       .13561+005

TIME =   .3300        RATE =      .29574+002         POSITION =   .49416+001
               TRM4,TRM5,TRM6:    .92669+000     .18106-243       .13985+005

TIME =   .3400        RATE =      .30436+002         POSITION =   .52417+001
               TRM4,TRM5,TRM6:    .92456+000     .74419-251       .14409+005

TIME =   .3500        RATE =      .31295+002         POSITION =   .55504+001
               TRM4,TRM5,TRM6:    .92243+000     .30589-258       .14832+005

TIME =   .3600        RATE =      .32153+002         POSITION =   .58676+001
               TRM4,TRM5,TRM6:    .92030+000     .12573-265       .15256+005

TIME =   .3700        RATE =      .33009+002         POSITION =   .61934+001
               TRM4,TRM5,TRM6:    .91818+000     .51678-273       .15680+005

TIME =   .3800        RATE =      .33862+002         POSITION =   .65278+001
               TRM4,TRM5,TRM6:    .91606+000     .21241-280       .16104+005

TIME =   .3900        RATE =      .34714+002         POSITION =   .68706+001
               TRM4,TRM5,TRM6:    .91395+000     .87308-288       .16527+005

TIME =   .4000        RATE =      .35563+002         POSITION =   .72220+001
               TRM4,TRM5,TRM6:    .91185+000     .35886-295       .16951+005

TIME =   .4100        RATE =      .36411+002         POSITION =   .75819+001
               TRM4,TRM5,TRM6:    .90975+000     .14750-302       .17375+005

TIME =   .4200        RATE =      .37257+002         POSITION =   .79503+001
               TRM4,TRM5,TRM6:    .90765+000     .00000           .17799+005

TIME =   .4300        RATE =      .38101+002         POSITION =   .83270+001
               TRM4,TRM5,TRM6:    .90556+000     .00000           .18223+005

TIME =   .4400        RATE =      .38943+002         POSITION =   .87123+001
               TRM4,TRM5,TRM6:    .90347+000     .00000           .18646+005

TIME =   .4500        RATE =      .39783+002         POSITION =   .91059+001
               TRM4,TRM5,TRM6:    .90139+000     .00000           .19070+005
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TIME =   .4600        RATE =   .40621+002        POSITION =   .95079+001
              TRM4,TRM5,TRM6:   .89931+000       .00000         .19494+005

TIME =   .4700        RATE =   .41457+002        POSITION =   .99163+001
              TRM4,TRM5,TRM6:   .89724+000       .00000         .19918+005

TIME =   .4800        RATE =   .42291+002        POSITION =   .10337+002
              TRM4,TRM5,TRM6:   .89517+000       .00000         .20341+005

TIME =   .4900        RATE =   .43123+002        POSITION =   .10764+002
              TRM4,TRM5,TRM6:   .89311+000       .00000         .20765+005

TIME =   .5000        RATE =   .43953+002        POSITION =   .11199+002
              TRM4,TRM5,TRM6:   .89105+000       .00000         .21189+005

TIME =   .5100        RATE =   .44782+002        POSITION =   .11643+002
              TRM4,TRM5,TRM6:   .88900+000       .00000         .21613+005

TIME =   .5200        RATE =   .45608+002        POSITION =   .12095+002
              TRM4,TRM5,TRM6:   .88695+000       .00000         .22037+005

TIME =   .5300        RATE =   .46433+002        POSITION =   .12555+002
              TRM4,TRM5,TRM6:   .88491+000       .00000         .22460+005

TIME =   .5400        RATE =   .47255+002        POSITION =   .13024+002
              TRM4,TRM5,TRM6:   .88267+000       .00000         .22884+005

TIME =   .5500        RATE =   .48076+002        POSITION =   .13500+002
              TRM4,TRM5,TRM6:   .88083+000       .00000         .23308+005

TIME =   .5600        RATE =   .48895+002        POSITION =   .13985+002
              TRM4,TRM5,TRM6:   .87880+000       .00000         .23732+005

TIME =   .5700        RATE =   .49712+002        POSITION =   .14478+002
              TRM4,TRM5,TRM6:   .87678+000       .00000         .24155+005

TIME =   .5800        RATE =   .50527+002        POSITION =   .14980+002
              TRM4,TRM5,TRM6:   .87476+000       .00000         .24579+005

TIME =   .5900        RATE =   .51340+002        POSITION =   .15489+002
              TRM4,TRM5,TRM6:   .87274+000       .00000         .25003+005

TIME =   .6000        RATE =   .52152+002        POSITION =   .16006+002
              TRM4,TRM5,TRM6:   .87073+000       .00000         .25427+005

TIME =   .6100        RATE =   .52961+002        POSITION =   .16532+002
              TRM4,TRM5,TRM6:   .86872+000       .00000         .25851+005

TIME =   .6200        RATE =   .53769+002        POSITION =   .17066+002
              TRM4,TRM5,TRM6:   .86672+000       .00000         .26274+005

TIME =   .6300        RATE =   .54575+002        POSITION =   .17607+002
              TRM4,TRM5,TRM6:   .86472+000       .00000         .26698+005

TIME =   .6400        RATE =   .55379+002        POSITION =   .18157+002
              TRM4,TRM5,TRM6:   .86273+000       .00000         .27122+005
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```
TIME =   .6500        RATE =    .56161+002       POSITION =    .18715+002
              TRM4,TRM5,TRM6:    .86074+000    .00000         .27546+005

TIME =   .6600        RATE =    .56981+002       POSITION =    .19261+002
              TRM4,TRM5,TRM6:    .85876+000    .00000         .27969+005

TIME =   .6700        RATE =    .57779+002       POSITION =    .19854+002
              TRM4,TRM5,TRM6:    .85678+000    .00000         .28393+005

TIME =   .6800        RATE =    .58576+002       POSITION =    .20436+002
              TRM4,TRM5,TRM6:    .85481+000    .00000         .28817+005

TIME =   .6900        RATE =    .59370+002       POSITION =    .21026+002
              TRM4,TRM5,TRM6:    .85284+000    .00000         .29241+005

TIME =   .7000        RATE =    .60163+002       POSITION =    .21624+002
              TRM4,TRM5,TRM6:    .85087+000    .00000         .29665+005

TIME =   .7100        RATE =    .60954+002       POSITION =    .22229+002
              TRM4,TRM5,TRM6:    .84891+000    .00000         .30088+005

TIME =   .7200        RATE =    .61744+002       POSITION =    .22843+002
              TRM4,TRM5,TRM6:    .84695+000    .00000         .30512+005

TIME =   .7300        RATE =    .62531+002       POSITION =    .23464+002
              TRM4,TRM5,TRM6:    .84500+000    .00000         .30936+005

TIME =   .7400        RATE =    .63316+002       POSITION =    .24093+002
              TRM4,TRM5,TRM6:    .84306+000    .00000         .31360+005

TIME =   .7500        RATE =    .64100+002       POSITION =    .24730+002
              TRM4,TRM5,TRM6:    .84111+000    .00000         .31784+005

TIME =   .7600        RATE =    .64882+002       POSITION =    .25375+002
              TRM4,TRM5,TRM6:    .83917+000    .00000         .32207+005

TIME =   .7700        RATE =    .65662+002       POSITION =    .26028+002
              TRM4,TRM5,TRM6:    .83724+000    .00000         .32631+005

TIME =   .7800        RATE =    .66441+002       POSITION =    .26689+002
              TRM4,TRM5,TRM6:    .83531+000    .00000         .33055+005

TIME =   .7900        RATE =    .67217+002       POSITION =    .27357+002
              TRM4,TRM5,TRM6:    .83339+000    .00000         .33479+005

TIME =   .8000        RATE =    .67992+002       POSITION =    .28033+002
              TRM4,TRM5,TRM6:    .83147+000    .00000         .33902+005

TIME =   .8100        RATE =    .68765+002       POSITION =    .28717+002
              TRM4,TRM5,TRM6:    .82955+000    .00000         .34326+005

TIME =   .8200        RATE =    .69536+002       POSITION =    .29408+002
              TRM4,TRM5,TRM6:    .82764+000    .00000         .34750+005

TIME =   .8300        RATE =    .70306+002       POSITION =    .30107+002
              TRM4,TRM5,TRM6:    .82573+000    .00000         .35174+005
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```
TIME =   .8400       RATE =    .71075+002        POSITION =    .30814+002
              TRM4,TRM5,TRM6:   .82383+000       .00000         .35595+005

TIME =   .8500       RATE =    .71857+002        POSITION =    .31529+002
              TRM4,TRM5,TRM6:   .82193+000       .00000         .36021+005

TIME =   .8600       RATE =    .72665+002        POSITION =    .32251+002
              TRM4,TRM5,TRM6:   .82004+000       .00000         .36445+005

TIME =   .8700       RATE =    .73366+002        POSITION =    .32961+002
              TRM4,TRM5,TRM6:   .81815+000       .00000         .36869+005

TIME =   .8800       RATE =    .74126+002        POSITION =    .33718+002
              TRM4,TRM5,TRM6:   .81626+000       .00000         .37293+005

TIME =   .8900       RATE =    .74885+002        POSITION =    .34463+002
              TRM4,TRM5,TRM6:   .81438+000       .00000         .37716+005

TIME =   .9000       RATE =    .75642+002        POSITION =    .35216+002
              TRM4,TRM5,TRM6:   .81250+000       .00000         .38140+005

TIME =   .9100       RATE =    .76393+002        POSITION =    .35976+002
              TRM4,TRM5,TRM6:   .81063+000       .00000         .38564+005

TIME =   .9200       RATE =    .77151+002        POSITION =    .36744+002
              TRM4,TRM5,TRM6:   .80876+000       .00000         .38988+005

TIME =   .9300       RATE =    .77903+002        POSITION =    .37519+002
              TRM4,TRM5,TRM6:   .80690+000       .00000         .39412+005

TIME =   .9400       RATE =    .78653+002        POSITION =    .38302+002
              TRM4,TRM5,TRM6:   .80504+000       .00000         .39835+005

TIME =   .9500       RATE =    .79402+002        POSITION =    .39092+002
              TRM4,TRM5,TRM6:   .80318+000       .00000         .40259+005

TIME =   .9600       RATE =    .80148+002        POSITION =    .39890+002
              TRM4,TRM5,TRM6:   .80133+000       .00000         .40683+005

TIME =   .9700       RATE =    .80893+002        POSITION =    .40695+002
              TRM4,TRM5,TRM6:   .79949+000       .00000         .41107+005

TIME =   .9800       RATE =    .81637+002        POSITION =    .41508+002
              TRM4,TRM5,TRM6:   .79765+000       .00000         .41530+005

TIME =   .9900       RATE =    .82376+002        POSITION =    .42328+002
              TRM4,TRM5,TRM6:   .79581+000       .00000         .41954+005

TIME =  1.0000       RATE =    .83118+002        POSITION =    .43156+002
              TRM4,TRM5,TRM6:   .79397+000       .00000         .42378+005

STOP    9999

@PACK R.
FURPUR 27R3A     L36-SL74R1 04/17/69 13:55:06
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LADSS* AML30I

```
RFTN,S L.MAIN
FTN 9R1  *04/17/80-14:03:12,)
          COMMON /STASTO/ Y(30),YD(30)
          COMMON / STEP/ DT,NIT,NSYS,H024
          EQUIVALENCE (Y(1),P),(YD(1),PD)
          EQUIVALENCE (Y(2),V),(YD(2),VD)
          EQUIVALENCE (Y(3),XR),(YD(3),XRD)
          EQUIVALENCE (Y(4),X),(YD(4),XD)
          NSYS = 4
          READ(5,90) DT
     90   FORMAT(7X,E10.0)
          READ (5,100) STPTH,ST,DP,PIN
          H024 = DT/24.0
          DO 10 I = 1,30
            Y(I) = 0.0
            YD(I) = 0.0
     10   CONTINUE
          READ(5,100) AO,ELA,RA,RSB,EKT,EN,EJM,EJL,FM,FL,EKE,TAUA
    100   FORMAT(7X,F10.0)
          P = 0.0
          T = 0.0
          NIT = 0
          TP = T + DP
          WRITE(6,300) DT,STPTH,ST,DP,AO,ELA,RA,RSB,EKT,EN,EJM,EJL,FM,FL,
         &EKE,TAUA
    300   FORMAT('1DT,STPTH,ST,DP = ',4F10.6,/,
         &' AO,LA,RA,RSB: ',G10.5,3(3X,F10.5),/,
         &' KT,N,JM,JL: ',4(F10.5,3X),/,
         &' FM,FL,KE,TAUA: ',4(F10.5,3X),/,
         &'0',6X,'TIME',12X,'P',14X,'R',13X,'XR',
         &13X,'Y')
          EJT = EN*EN*EJM + EJL
          FT = EN*EN*FM + FL
     20   E = P - RSB*V
C         SYMMETRIC LIMITER
          P = AMIN1(AMAX1(P,-26.0),26.0)
          PD = (E*AO - P)/TAUA
          U = P - EN*EKE*XP
          VD = (U - V*R)/ELA
          W = V*EKT*EN
          XRD = (W - XR*FT)/EJT
          XD = XR
          CALL EQINT
          T = T + DT
          NIT = NIT + 1
          IF(T .GE. STPTH) P = PIN
          IF(T .GE. ST) GO TO 30
          IF(((T + DT) .LT. TP) .AND. (NIT .GE. 10)) GO TO 20
     30   WRITE(6,200) T,P,R,XR,X, U,V,W,XD,XRD
    200   FORMAT('0',5G15.5,/,' ',10X,'U,V,W,XD,XRD: ',5G15.5)
          TP = TP + DP
          IF(T .LT. ST) GO TO 20
          STOP
          END

END FTN 114 IBANK 190 DBANK 64 COMMON
```

```
@FTN,S L.EQINT
FTN RR1  *04/17/80-14:03(3,)
      SUBROUTINE EQINT
      COMMON /STASTO/ Y(30),YD(30)
      COMMON /STEP/ DT,NIT,NSYS,HO24
      DIMENSION C(4),FSAV(30,4)
      DATA C/-9.0,37.0,-59.0,55.0/
      DATA FSAV/120*0.0/
      IF(NIT .GE. 3) GO TO 20
C
C   USE EULERS METHOD TO START
C
      DO 10 I=1,NSYS
         FSAV(I,1) = FSAV(I,2)
         FSAV(I,2) = FSAV(I,3)
         FSAV(I,3) = FSAV(I,4)
         FSAV(I,4) = YD(I)
         Y(I) = Y(I) + DT*FSAV(I,4)
   10 CONTINUE
      GO TO 40
C
C   ADAMS -BASHFORTH
C
   20 DO 30 I=1,NSYS
         SUM = 0.0
         FSAV(I,1) = FSAV(I,2)
         FSAV(I,2) = FSAV(I,3)
         FSAV(I,3) = FSAV(I,4)
         FSAV(I,4) = YD(I)
         SUM = SUM + C(1)*FSAV(I,1)
         SUM = SUM + C(2)*FSAV(I,2)
         SUM = SUM + C(3)*FSAV(I,3)
         SUM = SUM + C(4)*FSAV(I,4)
         Y(I) = Y(I) + HO24*SUM
   30 CONTINUE
   40 RETURN
      END

END FTN 68 IBANK 133 DBANK 64 COMMON
```

```
LADSS*AHL30I(1).OGCMTOR
      1       DT      *     .50E-6
      2       STPTM   *       0.0
      3       ST      *       1.0
      4       DP      *       .01
      5       PIN     *       1.0
      6       AO      *  100000.0
      7       LA      *     .0014
      8       RA      *       3.0
      9       RSB     *       1.0
     10       KT      *      24.8
     11       N       *       8.5
     12       JM      *      .016
     13       JL      *      3.30
     14       FM      *       0.0
     15       FL      *      .706
     16       KE      *      .177
     17       TAUA    *       .02

@XQT L.PROG
```

```
DT,STPTM,ST,DP =    .000000    .000010   1.000000    .010000
AO,LA,RA,RSD:  .10000+006     .00140      3.00000     1.00000
KT,N,JM,JL:     24.80000     8.50000      .01660      3.30000
FM,FL,KE,TAUA:    .00000      .70600      .17700      .02000

        TIME           P             R              XR              X

   .50000-006      1.0000         .00000          .00000          .00000
     U,V,W,XD,XRD:         .00000          .00000          .00000          .00000          .00000

   .10000-005      1.0000        2.5000           .00000          .00000
     U,V,W,XD,XRD:         .00000          .00000          .00000          .00000          .00000

   .15000-005      1.0000        4.9999           .00000          .00000
     U,V,W,XD,XRD:        2.5000       .89286-003         .00000          .00000          .00000

   .20000-005      1.0000        8.4322       .48398-007          .00000
     U,V,W,XD,XRD:        4.9999       .27879-002         .18821          .00000       .42238-001

   .25000-005      1.0000        10.921       .14760-006      .55456-013
     U,V,W,XD,XRD:        8.4322       .66714-002         .58770       .48398-007       .13189

   .30000-005      1.0000        13.397       .37968-006      .16509-012
     U,V,W,XD,XRD:        10.921       .10614-001         1.4063       .14760-006       .31561

   .35000-005      1.0000        15.867       .66086-006      .45602-012
     U,V,W,XD,XRD:        13.397       .15951-001         2.2375       .37968-006       .50214

   .40000-005      1.0000        18.317       .11268-005      .85127-012
     U,V,W,XD,XRD:        15.867       .22038-001         3.3624       .66086-006       .75457

   .45000-005      1.0000        20.753       .17218-005      .15951-011
     U,V,W,XD,XRD:        18.317       .28985-001         4.6455       .11268-005       1.0425

   .10000+000      1.0000        10.061         4.6934          .23540
     U,V,W,XD,XRD:        2.9996         .99989           210.78          4.6934          46.558

   .11000          1.0000        10.761         5.1589          .28471
     U,V,W,XD,XRD:        2.9996         .99988           210.77          5.1589          46.484

   .12000          1.0000        11.460         5.6234          .33867
     U,V,W,XD,XRD:        2.9996         .99987           210.77          5.6234          46.410

   .13000          1.0000        12.158         6.0873          .39729
     U,V,W,XD,XRD:        2.9996         .99986           210.77          6.0873          46.336

   .14000          1.0000        12.855         6.5506          .46054
     U,V,W,XD,XRD:        2.9996         .99986           210.77          6.5506          46.262

   .15000          1.0000        13.550         7.0128          .52842
     U,V,W,XD,XRD:        2.9995         .99985           210.77          7.0128          46.189

   .16000          1.0000        14.245         7.4746          .60090
     U,V,W,XD,XRD:        2.9995         .99984           210.77          7.4746          46.115

   .17000          1.0000        14.938         7.9355          .67800
     U,V,W,XD,XRD:        2.9995         .99984           210.77          7.9355          46.042
```

.18000	1.0000	15.631	8.3949	.75971	
U,V,W,XD,XRD:	2.9995	.99983	210.76	8.3949	45.969
.19000	1.0000	16.312	8.8534	.84602	
U,V,W,XD,XRD:	2.9994	.99982	210.76	8.8534	45.896
.20000	1.0000	17.009	9.3119	.93692	
U,V,W,XD,XRD:	2.9994	.99982	210.76	9.3119	45.823
.21000	1.0000	17.698	9.7696	1.0324	
U,V,W,XD,XRD:	2.9994	.99981	210.76	9.7695	45.750
.22000	1.0000	18.384	10.226	1.1324	
U,V,W,XD,XRD:	2.9994	.99980	210.76	10.226	45.678
.23000	1.0000	19.070	10.682	1.2369	
U,V,W,XD,XRD:	2.9994	.99980	210.76	10.682	45.605
.24000	1.0000	19.756	11.138	1.3461	
U,V,W,XD,XRD:	2.9993	.99979	210.76	11.138	45.532
.25000	1.0000	20.439	11.591	1.4597	
U,V,W,XD,XRD:	2.9993	.99978	210.75	11.591	45.460
.26000	1.0000	21.121	12.045	1.5780	
U,V,W,XD,XRD:	2.9993	.99978	210.75	12.045	45.388
.27000	1.0000	21.804	12.499	1.7007	
U,V,W,XD,XRD:	2.9993	.99977	210.75	12.499	45.316
.28000	1.0000	22.484	12.951	1.8280	
U,V,W,XD,XRD:	2.9993	.99976	210.75	12.951	45.244
.29000	1.0000	23.163	13.402	1.9599	
U,V,W,XD,XRD:	2.9992	.99975	210.75	13.402	45.172
.30000	1.0000	23.842	13.853	2.0961	
U,V,W,XD,XRD:	2.9992	.99975	210.75	13.853	45.100
.31000	1.0000	24.519	14.304	2.2368	
U,V,W,XD,XRD:	2.9992	.99974	210.75	14.304	45.029
.32000	1.0000	25.195	14.753	2.3821	
U,V,W,XD,XRD:	2.9992	.99973	210.74	14.753	44.957
.33000	1.0000	25.870	15.202	2.5318	
U,V,W,XD,XRD:	2.9992	.99973	210.74	15.202	44.886
.34000	1.0000	26.395	15.620	2.6859	
U,V,W,XD,XRD:	2.4991	.84185	177.46	15.620	37.351
.35000	1.0000	26.815	15.952	2.8438	
U,V,W,XD,XRD:	2.0008	.67384	142.05	15.952	29.350
.36000	1.0000	27.143	16.211	3.0046	
U,V,W,XD,XRD:	1.6199	.54238	114.33	16.211	23.090

.37000	1.0000	27.491	16.414	3.1678		
U,V,W,XD,XRD:	1.3950	.43326	92.596	16.414	18.179	
.38000	1.0000	27.604	16.574	3.3327		
U,V,W,XD,XRD:	1.0648	.35939	75.530	16.574	14.324	
.39000	1.0000	27.763	16.699	3.4991		
U,V,W,XD,XRD:	.87639	.29473	62.130	16.699	11.297	
.40000	1.0000	27.887	16.797	3.6665		
U,V,W,XD,XRD:	.72837	.24483	51.610	16.797	8.9207	
.41000	1.0000	27.985	16.875	3.8349		
U,V,W,XD,XRD:	.61212	.20563	43.348	16.875	7.0545	
.42000	1.0000	28.062	16.935	4.0039		
U,V,W,XD,XRD:	.52095	.17489	36.867	16.935	5.5903	
.43000	1.0000	28.122	16.983	4.1735		
U,V,W,XD,XRD:	.44736	.15079	31.787	16.983	4.4427	
.44000	1.0000	28.170	17.020	4.3430		
U,V,W,XD,XRD:	.39323	.13186	27.796	17.020	3.5412	
.45000	1.0000	28.207	17.050	4.5127		
U,V,W,XD,XRD:	.34869	.11682	24.626	17.050	2.8251	
.46000	1.0000	28.236	17.073	4.6834		
U,V,W,XD,XRD:	.31441	.10525	22.187	17.073	2.2742	
.47000	1.0000	28.259	17.091	4.8542		
U,V,W,XD,XRD:	.28708	.96029-001	20.243	17.091	1.8350	
.48000	1.0000	28.277	17.105	5.0249		
U,V,W,XD,XRD:	.26552	.88842-001	18.728	17.105	1.4928	
.49000	1.0000	28.291	17.115	5.1957		
U,V,W,XD,XRD:	.24784	.83504-001	17.603	17.115	1.2386	
.50000	1.0000	28.303	17.125	5.3664		
U,V,W,XD,XRD:	.23547	.78713-001	16.593	17.125	1.0105	
.51000	1.0000	28.310	17.131	5.5372		
U,V,W,XD,XRD:	.22650	.75611-001	15.939	17.131	.86273	
.52000	1.0000	28.316	17.136	5.7079		
U,V,W,XD,XRD:	.21931	.73215-001	15.434	17.136	.74866	
.53000	1.0000	28.322	17.140	5.8787		
U,V,W,XD,XRD:	.21213	.70820-001	14.929	17.140	.63459	
.54000	1.0000	28.328	17.145	6.0494		
U,V,W,XD,XRD:	.20494	.68425-001	14.424	17.145	.52052	
.55000	1.0000	28.331	17.147	6.2201		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	

.56000	1.0000	28.331	17.147	6.3909		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.57000	1.0000	28.331	17.147	6.5616		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.58000	1.0000	28.331	17.147	6.7324		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.59000	1.0000	28.331	17.147	6.9031		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.60000	1.0000	28.331	17.147	7.0739		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.61000	1.0000	28.331	17.147	7.2446		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.62000	1.0000	28.331	17.147	7.4154		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.63000	1.0000	28.331	17.147	7.5861		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.64000	1.0000	28.331	17.147	7.7569		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.65000	1.0000	28.331	17.147	7.9276		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.66000	1.0000	28.331	17.147	8.0977		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.67000	1.0000	28.331	17.147	8.2672		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.68000	1.0000	28.331	17.147	8.4368		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.69000	1.0000	28.331	17.147	8.6063		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.70000	1.0000	28.331	17.147	8.7759		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.71000	1.0000	28.331	17.147	8.9454		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.72000	1.0000	28.331	17.147	9.1150		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.73000	1.0000	28.331	17.147	9.2845		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	
.74000	1.0000	28.331	17.147	9.4541		
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158	

.75000	1.0000	28.331	17.147	9.6236	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.76000	1.0000	28.331	17.147	9.7932	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.77000	1.0000	28.331	17.147	9.9627	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.78000	1.0000	28.331	17.147	10.132	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.79000	1.0000	28.331	17.147	10.302	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.80000	1.0000	28.331	17.147	10.471	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.81000	1.0000	28.331	17.147	10.641	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.82000	1.0000	28.331	17.147	10.811	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.83000	1.0000	28.331	17.147	10.980	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.84000	1.0000	28.331	17.147	11.150	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.85000	1.0000	28.331	17.147	11.319	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.86000	1.0000	28.331	17.147	11.489	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.87000	1.0000	28.331	17.147	11.658	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.88000	1.0000	28.331	17.147	11.828	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.89000	1.0000	28.331	17.147	11.997	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.90000	1.0000	28.331	17.147	12.167	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.91000	1.0000	28.331	17.147	12.336	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.92000	1.0000	28.331	17.147	12.506	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158
.93000	1.0000	28.331	17.147	12.676	
U,V,W,XD,XRD:	.20219	.67397-001	14.207	17.147	.47158

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.94000            1.0000          28.331          17.147            12.845
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
.95000            1.0000          28.331          17.147            13.015
      U,V,W,X ,XRD:       .20219          .67397-001      14.207            17.147          .47158
.96000            1.0000          28.331          17.147            13.184
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
.97000            1.0000          28.331          17.147            13.354
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
.98000            1.0000          28.331          17.147            13.523
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
.99000            1.0000          28.331          17.147            13.693
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
1.0000            1.0000          28.331          17.147            13.862
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158
1.0000            1.0000          28.331          17.147            13.862
      U,V,W,XD,XRD:       .20219          .67397-001      14.207            17.147          .47158

QPRT L.IGCNTOR
FURPUR 27R3A     E36 SL24R1 04/17/80 14:10:37
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LADSS*AML30(1).IGCHTOR
     1        DT     =     .50E-6
     2        STPTM  =       0.0
     3        ST     =       1.0
     4        DP     =       .01
     5        PIN    =       1.0
     6        AO     =  100000.0
     7        LA     =    .00273
     8        RA     =     2.317
     9        RSB    =       1.0
    10        KT     =     19.75
    11        N      =      12.8
    12        JM     =     .0015
    13        JL     =      2.47
    14        FM     =       0.0
    15        FL     =      .622
    16        KE     =      .141
    17        TAUA   =       .02

@XQT L.PROG
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DI,STPTM,ST,DP =     .000600    .010000   1.000000   .010000
AO,LA,RA,RSB:  .10000+006       .30278     9.31790    1.00000
KT,N,JN,JL:    19.75000      12.60000      .00150     2.47000
FM,FL,KE,TAUA:      .00000      .62200      .14100      .02000

        TIME           P              R             XR             X

     .50000-006     1.0000         .00000        .00000        .00000
     U,V,W,XD,XRD:          .00000        .00000        .00000        .00000        .00000

     .10000-005     1.0000         2.5000        .00000        .00000
     U,V,W,XD,XRD:          .00000        .00000        .00000        .00000        .00000

     .15000-005     1.0000         4.9999        .00000        .00000
     U,V,W,XD,XRD:          2.5000        .44964-003    .00000        .00000        .00000

     .20000-005     1.0000         8.4347        .47959-007    .00000
     U,V,W,XD,XRD:          4.9999        .14034-002    .11367        .00000        .41855-001

     .25000-005     1.0000         10.929        .14620-006    .54953-013
     U,V,W,XD,XRD:          8.4347        .33587-002    .35477        .47959-007    .13063

     .30000-005     1.0000         13.417        .37615-006    .16352-012
     U,V,W,XD,XRD:          10.929        .53437-002    .84912        .14620-006    .31266

     .35000-005     1.0000         15.701        .65464-006    .45180-012
     U,V,W,XD,XRD:          13.417        .80328-002    1.3509        .37615-006    .49742

     .40000-005     1.0000         18.376        .11165-005    .84326-012
     U,V,W,XD,XRD:          15.701        .11100-001    2.0307        .65464-006    .74774

     .45000-005     1.0000         20.844        .17061-005    .15805-011
     U,V,W,XD,XRD:          18.376        .14605-001    2.8060        .11165-005    1.0332

     .10000-000     1.0000         25.915        9.1983        .56174
     U,V,W,XD,XRD:          9.3142        .99971        252.73        9.1982        90.952

     .11000         1.0000         26.374        10.041        .55816
     U,V,W,XD,XRD:          7.8778        .84998        214.88        10.041        76.823

     .12000         1.0000         26.716        10.743        .66228
     U,V,W,XD,XRD:          6.6113        .71330        180.32        10.743        63.938

     .13000         1.0000         27.000        11.327        .77283
     U,V,W,XD,XRD:          5.5574        .59957        151.57        11.327        53.218

     .14000         1.0000         27.237        11.813        .88871
     U,V,W,XD,XRD:          4.6807        .50494        127.65        11.813        44.298

     .15000         1.0000         27.434        12.217        1.0090
     U,V,W,XD,XRD:          3.9511        .42621        107.75        12.217        36.877

     .16000         1.0000         27.598        12.553        1.1330
     U,V,W,XD,XRD:          3.3442        .36071        91.188        12.553        30.702

     .17000         1.0000         27.731        12.833        1.2600
     U,V,W,XD,XRD:          2.8392        .30621        77.410        12.833        25.565
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.18000	1.0000	27.847	13.066	1.3896		
U,V,W,XD,XRD:		2.4170	.26096	65.947	13.066	21.291
.19000	1.0000	27.942	13.259	.5213		
U,V,W,XD,XRD:		2.0694	.22314	56.409	13.259	17.734
.20000	1.0000	28.020	13.421	1.6548		
U,V,W,XD,XRD:		1.7785	.19174	48.473	13.421	14.775
.21000	1.0000	28.085	13.555	1.7898		
U,V,W,XD,XRD:		1.5366	.16543	41.971	13.555	12.313
.22000	1.0000	28.140	13.666	1.9260		
U,V,W,XD,XRD:		1.3352	.14390	36.377	13.666	10.265
.23000	1.0000	28.185	13.759	2.0631		
U,V,W,XD,XRD:		1.1676	.12581	31.806	13.759	8.5604
.24000	1.0000	28.222	13.836	2.2010		
U,V,W,XD,XRD:		1.0282	.11077	28.003	13.836	7.1424
.25000	1.0000	28.254	13.901	2.3397		
U,V,W,XD,XRD:		.91224	.98255-001	24.837	13.901	5.9626
.26000	1.0000	28.280	13.954	2.4789		
U,V,W,XD,XRD:		.81579	.87840-001	22.206	13.954	4.9808
.27000	1.0000	28.301	13.998	2.6186		
U,V,W,XD,XRD:		.73561	.79187-001	20.019	13.998	4.1652
.28000	1.0000	28.319	14.035	2.7587		
U,V,W,XD,XRD:		.66882	.71978-001	16.196	14.035	3.4856
.29000	1.0000	28.334	14.066	2.8990		
U,V,W,XD,XRD:		.61321	.65982-001	16.690	14.066	2.9204
.30000	1.0000	28.347	14.092	3.0399		
U,V,W,XD,XRD:		.56700	.60995-001	15.[illegible]	14.092	2.4503
.31000	1.0000	28.357	14.113	3.1808		
U,V,W,XD,XRD:		.52861	.56847-001	14.371	14.113	2.0593
.32000	1.0000	28.366	14.131	3.3219		
U,V,W,XD,XRD:		.49657	.53393-001	13.498	14.131	1.7338
.33000	1.0000	28.373	14.146	3.4634		
U,V,W,XD,XRD:		.46979	.50506-001	12.768	14.146	1.4616
.34000	1.0000	28.379	14.158	3.6048		
U,V,W,XD,XRD:		.44773	.48124-001	12.166	14.158	1.2371
.35000	1.0000	28.384	14.168	3.7463		
U,V,W,XD,XRD:		.42960	.46165-001	11.670	14.168	1.0524
.36000	1.0000	28.388	14.177	3.8878		
U,V,W,XD,XRD:		.41423	.44501-001	11.250	14.177	.89558

.37000	1.0000	28.392	14.184	4.0292	
U,V,W,XD,XRD:	.40130	.43114-001	10.899	14.184	.76475
.38000	1.0000	28.394	14.189	4.1709	
U,V,W,XD,XRD:	.39105	.42000-001	10.618	14.189	.65976
.39000	1.0000	28.397	14.194	4.3130	
U,V,W,XD,XRD:	.38243	.41074-001	10.384	14.194	.57254
.40000	1.0000	28.399	14.199	4.4551	
U,V,W,XD,XRD:	.37381	.40149-001	10.150	14.199	.48533
.41000	1.0000	28.400	14.202	4.5972	
U,V,W,XD,XRD:	.36908	.39628-001	10.018	14.202	.43618
.42000	1.0000	28.401	14.204	4.7393	
U,V,W,XD,XRD:	.36477	.39165-001	9.9010	14.204	.39258
.43000	1.0000	28.403	14.206	4.8814	
U,V,W,XD,XRD:	.36046	.38703-001	9.7840	14.206	.34897
.44000	1.0000	28.404	14.209	5.0235	
U,V,W,XD,XRD:	.35615	.38240-001	9.6671	14.209	.30536
.45000	1.0000	28.405	14.211	5.1656	
U,V,W,XD,XRD:	.35184	.37777-001	9.5501	14.211	.26175
.46000	1.0000	28.406	14.212	5.3076	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.47000	1.0000	28.406	14.212	5.4497	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.48000	1.0000	28.406	14.212	5.5918	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.49000	1.0000	28.406	14.212	5.7339	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.50000	1.0000	28.406	14.212	5.8760	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.51000	1.0000	28.406	14.212	6.0181	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.52000	1.0000	28.406	14.212	6.1602	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.53000	1.0000	28.406	14.212	6.3023	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.54000	1.0000	28.406	14.212	6.4444	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715
.55000	1.0000	28.406	14.212	6.5864	
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715

.56000	1.0000	28.406	14.212	6.7285		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.57000	1.0000	28.406	14.212	6.8706		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.58000	1.0000	28.406	14.212	7.0127		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.59000	1.0000	28.406	14.212	7.1548		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.60000	1.0000	28.406	14.212	7.2969		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.61000	1.0000	28.406	14.212	7.4390		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.62000	1.0000	28.406	14.212	7.5811		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.63000	1.0000	28.406	14.212	7.7232		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.64000	1.0000	28.406	14.212	7.8652		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.65000	1.0000	28.406	14.212	8.0073		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.66000	1.0000	28.406	14.212	8.1482		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.67000	1.0000	28.406	14.212	8.2891		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.68000	1.0000	28.406	14.212	8.4300		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.69000	1.0000	28.406	14.212	8.5709		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.70000	1.0000	28.406	14.212	8.7118		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.71000	1.0000	28.406	14.212	8.8526		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.72000	1.0000	28.406	14.212	8.9935		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.73000	1.0000	28.406	14.212	9.1344		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	
.74000	1.0000	28.406	14.212	9.2753		
U,V,W,XD,XRD:	.34954	.37516-001	9.4841	14.212	.23715	

.75000	U,V,P,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	9.4162	14.212	.23715
.76000	U,V,W,XD,XRD:	1.0000	.34754	28.406	.37516-001	14.212	9.4841	9.5571	14.212	.23715
.77000	U,V,W,XD,XRD:	1.0000	.34754	28.406	.37516-001	14.212	9.4841	9.6980	14.212	.23715
.78000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	9.8389	14.212	.23715
.79000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	9.9798	14.212	.23715
.80000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.121	14.212	.23715
.81000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.262	14.212	.23715
.82000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.403	14.212	.23715
.83000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.543	14.212	.23715
.84000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.684	14.212	.23715
.85000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.825	14.212	.23715
.86000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	10.966	14.212	.23715
.87000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.107	14.212	.23715
.88000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.248	14.212	.23715
.89000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.389	14.212	.23715
.90000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.530	14.212	.23715
.91000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.671	14.212	.23715
.92000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.811	14.212	.23715
.93000	U,V,W,XD,XRD:	1.0000	.34954	28.406	.37516-001	14.212	9.4841	11.952	14.212	.23715

```
 .94000        1.0000         28.406         14.212         12.093
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 .95000        1.0000         28.406         14.212         12.234
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 .96000        1.0000         28.406         14.212         12.375
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 .97000        1.0000         28.406         14.212         12.516
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 .98000        1.0000         28.406         14.212         12.657
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 .99000        1.0000         28.406         14.212         12.798
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 1.0000        1.0000         28.406         14.212         12.939
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

 1.0000        1.0000         28.406         14.212         12.939
     U,V,W,XD,XRD:      .34954         .37516-001     9.4841         14.212         .23715

@PACK L.
FURPUR 27R3A       E36 SL74R1 04/17/80 14:10:20
END PACK. TEX,=3,TOC=1,SYM=10,REL=2,ABS=1

@FIN
```

APPENDIX F
FREQUENCY RESPONSE ANALYSIS

Figure F-1 presents the fundamental block diagram on which the frequency domain analysis will be based.

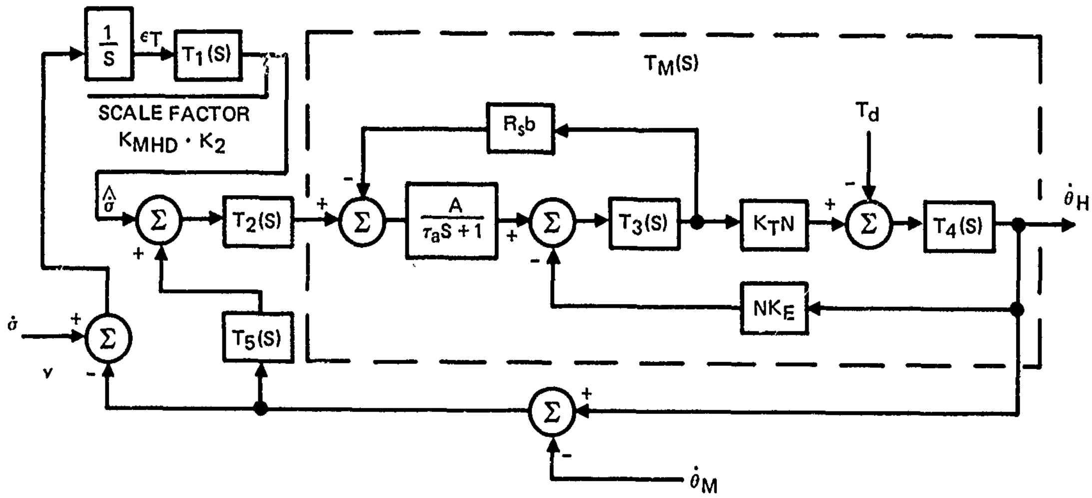

Figure F-1. Stabilized platform block diagram.

where

$$T_1(S) = \frac{K_4K_5}{\tau_7 S + 1}$$

$$T_2(S) = \frac{K_3(\tau_2 S + 1)^2 (\tau_5 S + 1)}{S(\tau_3 S + 1)^2 (\tau_6 S + 1)}$$

$$T_3(S) = \frac{1}{L_a S + R_a}$$

$$T_4(S) = \frac{1}{J_T S + D}$$

$$T_5(S) = \frac{K_{MHD}\, K_2}{(\tau_4 S + 1)^3}$$

Also let

$$T_m(S) = \frac{AK_T N}{(\tau_a S + 1)\,(L_a S + R_a)\,(J_T S + D) + AR_s b\,(J_T S + D) + (\tau_a S + 1)\, N^2\, K_E\, K_T}$$

which is the full torque motor transfer function. Six transfer functions will be derived for the frequency analysis:

$$1)\ \frac{\hat{\dot{\sigma}}}{\dot{\sigma}},\quad 2)\ \frac{\hat{\dot{\sigma}}}{T_d},\quad 3)\ \frac{\hat{\dot{\sigma}}}{\dot{\theta}_M},\quad 4)\ \frac{\hat{\dot{\sigma}}}{\dot{\theta}_H},\quad 5)\ \frac{\epsilon_T}{\dot{\theta}_M},\quad \text{and } 6)\ \frac{\epsilon_T}{T_d}.$$

All of these transfer functions are derived as per the conical form of figure F-2.

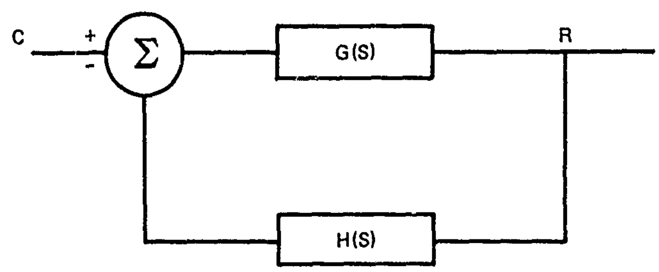

Figure F-2. Conical form block diagram.

where the transfer function of input to output is

$$\frac{R}{C} = \frac{G(S)}{1 + G(S)\,H(S)}. \tag{1}$$

For the first transfer function, $\hat{\dot{\sigma}}/\dot{\sigma}$, the block diagram of figure F-1 is rearranged as illustrated in figure F-3.

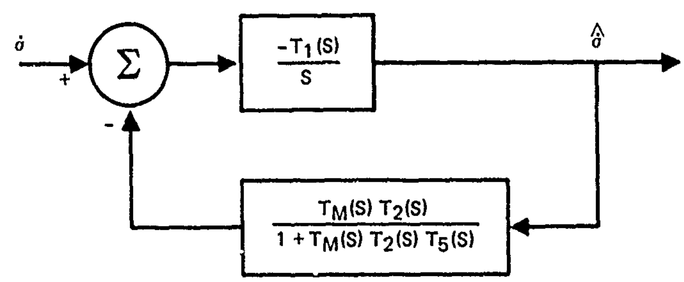

Figure F-3. Block diagram for $\hat{\dot{\sigma}}/\dot{\sigma}$ transfer function.

where

$$G_1(S) = \frac{-T_1(S)}{S} \tag{2}$$

$$H_1(S) = \frac{T_M(S)\, T_2(S)}{1 + T_M(S)\, T_2(S)\, T_S(S)} \tag{3}$$

$$\frac{\hat{\sigma}}{\dot{\sigma}} = \frac{1}{SF} \cdot \frac{G_1(S)}{1 + G_1(S)\, H_1(S)} \tag{4}$$

When the scale factor is incorporated into Eq. 4 $\hat{\sigma}$ is in the units of rad/sec. The scale factor is

$$SF = K_{MHD} \cdot K_2 . \tag{5}$$

For the second transfer function, $\hat{\sigma}/T_d$, the block diagram of figure F-1 is rearranged as illustrated in figure F-4.

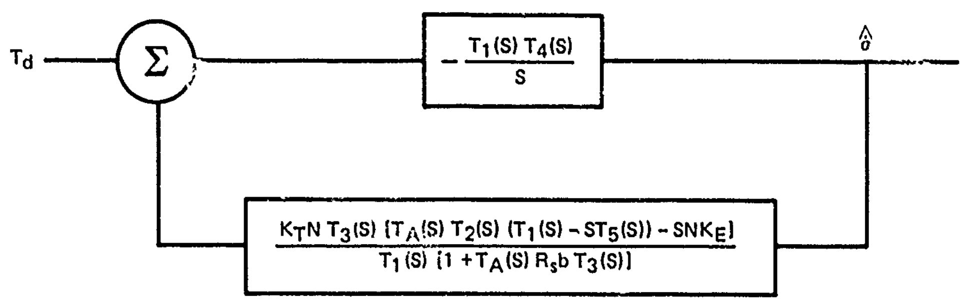

Figure F-4. Block diagram for $\hat{\sigma}/T_d$ transfer function.

where

$$G_2(S) = \frac{-\,T_1(S)\, T_4(S)}{S}, \tag{6}$$

$$H_2(S) = \frac{K_T N\, T_3(S)\, [T_A(S)\, T_2(S)\, (T_1(S) - ST_5(S)) - SNK_E]}{T_1(S)\, [1 + T_A(S)\, R_s b\, T_3(S)]} \tag{7}$$

and

$$\frac{\hat{\sigma}}{T_d} = \frac{1}{SF} \cdot \frac{G_2(S)}{1 + G_2(S)\, H_2(S)} . \tag{8}$$

For the third transfer function, $\hat{\sigma}/\dot{\theta}_M$, the block diagram of figure F-1 is rearranged as illustrated in figure F-5.

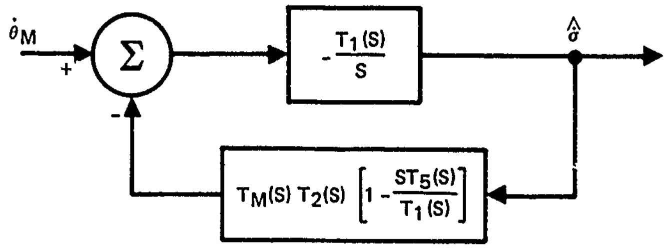

Figure F-5. Block diagram for $\hat{\sigma}/\dot{\theta}_M$ transfer function.

where

$$G_3(S) = \frac{-T_1(S)}{S}, \tag{9}$$

$$H_3(S) = T_M(S)\, T_2(S) \left[1 - \frac{ST_5(S)}{T_1(S)}\right], \tag{10}$$

and

$$\frac{\hat{\sigma}}{\dot{\theta}_M} = \frac{1}{SF} \cdot \frac{G_3(S)}{1 + G_3(S)\, H_3(S)} \tag{11}$$

For the fourth transfer function, $\hat{\sigma}/\dot{\theta}_H$, the block diagram of figure F-1 is rearranged as illustrated in figure F-6.

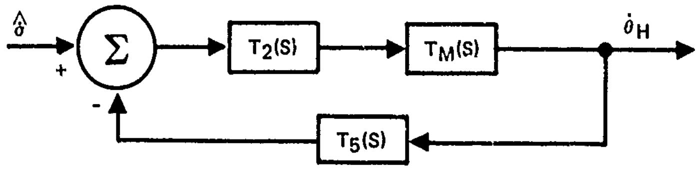

Figure F-6. Block diagram for $\hat{\sigma}/\dot{\theta}_H$ transfer function.

where

$$G_4(S) = T_2(S)\, T_M(S), \tag{12}$$

$$H_4(S) = T_5(S), \tag{13}$$

and

$$\frac{\hat{\sigma}}{\dot{\theta}_H} = \frac{1}{SF} \cdot \frac{G_4(S)}{1 + G_4(S)\, H_4(S)} \tag{14}$$

For the fifth transfer function, $\epsilon_T/\dot{\theta}_M$, the block diagram of figure F-1 is rearranged as illustrated in figure F-7.

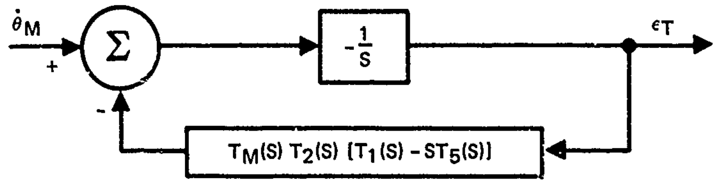

Figure F-7. Block diagram of $\epsilon_T/\dot{\theta}_M$ transfer function.

where

$$G_5(S) = \frac{-1}{S}, \tag{15}$$

$$H_5(S) = T_M(S)\, T_2(S)\, [T_1(S) - ST_5(S)], \tag{16}$$

and

$$\frac{\epsilon_T}{\dot{\theta}_M} = \frac{G_5(S)}{1 + G_5(S)\, H_5(S)} \tag{17}$$

For the sixth transfer function, ϵ_T/T_d, the block diagram of figure F-1 is rearranged as illustrated in figure F-8.

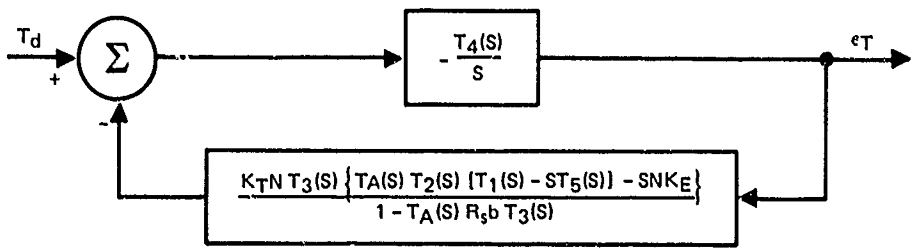

Figure F-8 Block diagram of ϵ_T/T_d transfer function.

where

$$G_6(S) = \frac{-T_4(S)}{S}, \tag{18}$$

$$H_6(S) = \frac{K_T N\, T_3(S) \left\{ T_A(S)\, T_2(S)\, [T_1(S) - ST_5(S)] - SNK_E \right\}}{1 - T_A(S)\, R_s b\, T_3(S)} \tag{19}$$

and

$$\frac{\epsilon_T}{T_d} = \frac{G_6(S)}{1 + G_6(S)\, H_6(S)} \tag{20}$$

LADSS* TMPFR

```
@FTN,RODS L.MAIN
FTN 8R1  *04/16/80-14:18(2,)
          COMPLEX S,TFRFCT,LOOPG,G,H,TEMP1,TEMP2
    C       THIS PROGRAM COMPUTES THE FREQUENCY RESPONSE OF THE
    C          LADSS PLATFORM. SEVEN DIFFERENT RESPONSES CAN BE
    C          CHOSEN AS LISTED IN THE COMMENTS OF SUBROUTINES G & H.
    C
          INTEGER *4 KK1,KK2,KK3,KK4,KK5
          COMMON /GHTYPE/ I
          COMMON /SCALE/ SF
          COMMON /RANGE/ WMIN,NOCT
    C   SF IS KHHD*K2 WHICH IS THE SCALE FACTOR FOR SIGMA DOT HAT.
          CALL INPUT
    5     READ ( 5,105,END=99 ) KK1,KK2,KK3,KK4,KK5,I
    105   FORMAT ( 5A4,I2 )
          IF ( I .EQ. 0 ) GO TO 5
          WRITE ( 6,106 ) KK1,KK2,KK3,KK4,KK5,I
    106   FORMAT ( '1   ',5A4,I3,3X,'LADSS PLATFORM' )
          WRITE ( 6,200 )
    200   FORMAT('0 FREQUENCY',9X,'LOOP GAIN',18X,'RESPONSE',36X,'G',
         &   24X,'H',/,'   ','RADIANS',9X,'DB',7X,'DEGREES',9X,'DB',
         &   7X,'DEGREES',24X,'REAL',7X,'IMAG',10X,'REAL',7X,'IMAG',/,
         &   '  ',9('-'),2(3X,22('-')),17X,2(3X,22('-')))
          FAC1 = 20.0 / ALOG ( 10.0 )
          FAC2 = 180.0 / 3.14159265
          WINC = WMIN
          DO 20 J=1,NOCT
1            IF ( J .GT. 1 ) WINC = WMIN * ( 10.0** ( J-1 ) )
1            DO 10 K=1,9
2              W = FLOAT ( K ) * WINC
2              S = CMPLX ( 0.0,W )
2              TEMP1 = G ( S )
2              TEMP2 = H ( S )
2              LOOPG = TEMP1 * TEMP2
2              TFRFCT = TEMP1 / ( 1.0 + LOOPG )
2              IF ( I .LE. 3 ) TFRFCT = TFRFCT / CMPLX ( SF,0.0 )
2              LOOPG = CLOG ( LOOPG )
2              TFRFCT = CLOG ( TFRFCT )
2              V1 = REAL ( LOOPG ) * FAC1
2              V2 = AIMAG ( LOOPG ) * FAC2
2              V3 = REAL ( TFRFCT ) * FAC1
2              V4 = AIMAG ( TFRFCT ) * FAC2
2              WRITE ( 6,210 ) W,V1,V2,V3,V4,TEMP1,TEMP2
2   210        FORMAT ( ' ',F10.3,2 ( 3X,F10.3,2X,F10.3 ) ,17X,
2        &         2 ( 3X,2G11.5 ) )
2   10       CONTINUE
1   20    CONTINUE
          GO TO 5
    99    STOP
          END
```

```
@FTN,RODS L.INPUT
FTN 8R1  *04/16/80-14:18(1,)
          SUBROUTINE INPUT
          IMPLICIT REAL ( J,K,L,N )
          COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,
     &    TAU6,A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
          COMMON /RANGE/ WMIN,MOCT
          COMMON /SCALE/ SF
C    1.0/SF IS THE SCALE FACTOR FOR SIGMA DOT HAT FOR CONVERSION
C      FROM VOLTS TORADIANS PER SECOND.
          READ ( 5,100 ) K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,
     &    TAU6,A,TAUA
100       FORMAT ( 6X,F10.0 )
          READ ( 5,100 ) LA,RA,RSB,KT,N,JM,JL,D,KE,KMHD,K2,KF,TAU4
          READ ( 5,300 ) WMIN,MOCT,ISCLF
300       FORMAT ( F5.0,2I2 )
          SF = K2 * KMHD
          IF ( ISCLF .EQ. 0 ) SF = 1.0
          JT = N*N*JM + JL
          RETURN
          END
```

```
@FTN,RODS L.G
FTN 8R1  *04/16/80-14:18(4,)
      COMPLEX FUNCTION G ( S )
C   THIS FUNCTION COMPUTES G FOR CANONICAL FORM OF THE CONTROL
C      SUBSYSTEMS LISTED IN COMMENTS. CHOICE OF SUBSYSTEMS IS
C      INDICATED BY VARIABLE I IN COMMON AREA GHTYPE.
C
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE,T1,T2,T3,T4,T5,TM,TC1,TC2
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &   A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      COMMON /GHTYPE/ I
      DATA ONE / ( 1.0,0.0 ) /
      GO TO ( 10,20,30,40,50,60,70 ) , I
C
C   COMPLETE PLATFORM SIGMA DOT -TO- SIGMA DOT HAT.
C
10    G = T1 ( S ) / S
      RETURN
C
C   TORQUE DISTURBANCE -TO- SIGMA DOT HAT.
C
20    G = ( -T1 ( S ) * T4 ( S ) ) / S
      RETURN
C
C   BODY MOTION (THETA DOT M) -TO- SIGMA DOT HAT.
C
30    G = T1 ( S ) / S
      RETURN
C
C   TORQUE DISTURBANCE -TO- POINTING ERROR.
C
40    G = ( -T4 ( S ) ) / S
      RETURN
C
C   BODY MOTION (THETA DOT M) -TO- POINTING ERROR.
C
50    G = ( -ONE ) / S
      RETURN
C
C   STABILIZATION LOOP (SIGMA DOT HAT -TO- THETA DOT M).
C
60    G = T2 ( S ) * TM ( S )
      RETURN
C
C   SLAVE LOOP
C
70    TC1 = ( TAU2 * S + ONE ) * ( TAU2P * S + ONE )
      TC2 = ( TAU3 * S + ONE ) * ( TAU3P * S + ONE )
      TC1 = ( TC1 / TC2 ) * ( ONE / ( TAU6*S + ONE ) )
      G = K3 * TC1 * TM ( S ) * ( ONE / S )
      RETURN
      END
```

```
@FTN,RODS L,H
FTN 8R1  *04/16/80-14:18(3,)
      COMPLEX FUNCTION H ( S )
C   THIS FUNCTION COMPUTES H FOR CANONICAL FORM OF THE CONTROL
C     SUBSYSTEMS LISTED IN COMMENTS. CHOICE OF SUBSYSTEMS IS
C     INDICATED BY VARIABLE I IN COMMON AREA GHTYPE.
C
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE,T1,T2,T3,T4,T5,TM,T1S,T2S,T3S,T4S,T5S,TMS,HNUM,HDEN
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &  A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      COMMON /GHTYPE/ I
      DATA ONE / ( 1.0,0.0 ) /
      GO TO ( 10,20,30,40,50,60,70 ), I
C
C   COMPLETE PLATFORM SIGMA DOT -TO- SIGMA DOT HAT.
C
 10   TMS = TM ( S )
      T2S = T2 ( S )
      H = ( TMS * T2S ) / ( ONE + TMS*T2S*T5 ( S ) )
      RETURN
C
C   TORQUE DISTURBANCE -TO- SIGMA DOT HAT.
C
 20   T1S = T1 ( S )
      T3S = T3 ( S )
      TAS = ONE / ( TAUA*S + ONE )
      HNUM = KT*N*T3S* ( TAS*T2 ( S ) * ( T1S - S*T5 ( S )) - S*N*KE )
      HDEN = T1S* ( ONE + TAS*RSB*T3S )
      H = HNUM / HDEN
      RETURN
C
C   BODY MOTION (THETA DOT H) -TO- SIGMA DOT HAT.
C
 30   H = TM ( S ) * T2 ( S ) * ( ONE - ( S*T5 ( S ) / T1 ( S ) ) )
      RETURN
C
C   TORQUE DISTURBANCE -TO- POINTING ERROR.
C
 40   T1S = T1 ( S )
      T3S = T3 ( S )
      TAS = ONE / ( TAUA*S + ONE )
      HNUM = KT*N*T3S* ( TAS*T2 ( S ) * ( T1S - S*T5 ( S ) ) - S*N*KE )
      HDEN = ONE - TAS*RSB*T3S
      H = HNUM / HDEN
      RETURN
C
C   BODY MOTION (THETA DOT H) -TO- POINTING ERROR.
C
 50   H = TM ( S ) * T2 ( S ) * ( T1 ( S ) - S*T5 ( S ) )
      RETURN
C
C   STABILIZATION LOOP (SIGMA DOT HAT -TO- THETA DOT H).
C
 60   H = T5 ( S )
      RETURN
C
```

```
C     SLAVE LOOP
C
70    H = KHHD * K2 * KF
      RETURN
      END
```

```
@FTN,RODS 1.T1
FTN 8R1  *04/16/80-14:18(1,)
      COMPLEX FUNCTION T1 ( S )
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &   A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      DATA ONE / ( 1.0,0.0 ) /
      T1 = K4 + K5 / ( TAU7 * S + ONE )
      RETURN
      END
```

```
BFTN,RODS L.T2
FTN 8R1  .04/16/80-14:18(1,)
      COMPLEX FUNCTION T2 ( S )
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE,C1,C2,T2N,T2D
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &  A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      DATA ONE / ( 1.0,0.0 ) /
      C1 = (TAU2 * S + ONE) * (TAU2P * S + ONE)
      C2 = (TAU3 * S + ONE) * (TAU3P * S + ONE)
      T2N = K3 * C1 * (TAU5 * S + ONE)
      T2D = S * C2* (TAU6 * S + ONE)
      T2 = T2N / T2D
      RETURN
      END
```

```
@FTN,RODS L.T3
FTN 8R1  *04/16/80-14:18(0,)
      COMPLEX FUNCTION T3 ( S )
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &   A,TAUA,LA,RA,RSR,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      DATA ONE / ( 1.0,0.0 ) /
      T3 = ONE / (LA * S + RA)
      RETURN
      END
```

```
@FTN,RODS L.T4
FTN 8R1  *04/16/80-14:18(0,)
      COMPLEX FUNCTION T4 ( S )
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE
      COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &   A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      DATA ONE / ( 1.0,0.0 ) /
      T4 = ONE / ( JT * S + D)
      RETURN
      END
```

```
@FTN,RODS L.TS
FTN 8R;  *04/16/80-14:18(0,)
      COMPLEX FUNCTION TS ( S )
      IMPLICIT REAL ( J,K,L,N )
      COMPLEX S,ONE,C1
      COMMON /CONST/ KS,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
     &  A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHD,K2,KF,TAU4
      DATA ONE / ( 1.0,0.0 ) /
      C1 = TAU4 * S + ONE
      TS = KMHD * K2 / (C1*C1*C1)
      RETURN
      END
```

```
@FTN,ROOS L.TM
FTN 8R1  *04/16/80-14:18(0,)
          COMPLEX FUNCTION TM ( S )
          IMPLICIT REAL ( J,K,L,N )
          COMPLEX S,ONE,C1,C2,C3
          COMMON /CONST/ K5,K4,TAU7,K3,TAU2,TAU2P,TAU3,TAU3P,TAU5,TAU6,
         &   A,TAUA,LA,RA,RSB,KT,N,JT,D,KE,KMHS,K2,KF,TAU4
          DATA ONE / ( 1.0,0.0 ) /
          C1 = JT * S + D
          C2 = TAUA * S + ONE
          C3 = LA * S + RA
          TM = A*KT*N / ( C1*C2*C3 + A* RSB*C1 + N*N*KE*KT*C2 )
          RETURN
          END
```

```
LADSS*TMPFR(1).OGDATA/NEWJL
      1        K5     .        7.0
      2        K4     .        7.0
      3        TAU7   .        .025
      4        K3     .      84.720
      5        TAU2   .         .01
      6        TAU2P  .         .01
      7        TAU3   .       .0005
      8        TAU3P  .       .0005
      9        TAU5   .         0.1
     10        TAU6   .        0.80
     11        A      .    100000.0
     12        TAUA   .         .02
     13        LA     .       .0014
     14        RA     .         3.0
     15        RSB    .         1.0
     16        KT     .        24.6
     17        N      .         8.5
     18        JM     .        .016
     19        JL     .        3.30
     20        D      .        .706
     21        KE     .        .177
     22        KMHD   .       .8595
     23        K2     .        14.0
     24        KF     .         1.0
     25        TAU4   .       .0015
     26          .01 6 1
     27        SIG DOT - SIG DT H    1
     28        TRQ DIS - SIG DT H    2
     29        BOD MOT - SIG DT K    3
     30        TRQ DIS - PNT ERROR   4
     31        BOD MOT - PNT ERROR   5
     32        STABILIZATION LOOP    6

@XQT L.PROG
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SIG DOT - SIG DT H 1 LADSS PLATFORM

FREQUENCY	LOOP GAIN		RESPONSE		G		H	
RADIANS	DB	DEGREES	DB	DEGREES	REAL	IMAG	REAL	IMAG
.010	52.196	-90.012	.000	-.143	-1.2250	-4900.0	.83105-001	.37369-005
.020	46.176	-90.023	.000	-.287	-1.2250	-2450.0	.83105-001	.74738-005
.030	42.654	-90.035	-.000	-.430	-1.2250	-1633.3	.83105-001	.11211-004
.040	40.155	-90.047	-.000	-.573	-1.2250	-1225.0	.83105-001	.14948-004
.050	38.217	-90.059	-.001	-.716	-1.2250	-980.00	.83105-001	.18685-004
.060	36.633	-90.070	-.001	-.860	-1.2250	-816.66	.83105-001	.22422-004
.070	35.294	-90.082	-.001	-1.003	-1.2250	-700.00	.83105-001	.26159-00[illegible]
.080	34.135	-90.094	-.001	-1.146	-1.2250	-612.50	.83105-001	.[illegible]9896-[illegible]04
.090	33.112	-90.106	-.002	-1.289	-1.2250	-544.44	.83105-001	.33[illegible]-004
.100	32.196	-90.117	-.002	-1.433	-1.2250	-490.00	.83105-001	.37370-004
.200	26.176	-90.235	-.009	-2.864	-1.2250	-244.99	.83105-001	.74748-004
.300	22.654	-90.352	-.020	-4.293	-1.2249	-163.32	.83105-001	.11214-003
.400	20.155	-90.470	-.035	-5.718	-1.2249	-122.49	.83105-001	.14955-003
.500	18.216	-90.587	-.054	-7.138	-1.2248	-97.985	.83105-001	.18699-003
.600	16.633	-90.705	-.078	-8.552	-1.2247	-81.648	.83105-001	.22447-003
.700	15.293	-90.822	-.106	-9.958	-1.2246	-69.979	.83105-001	.26199-003
.800	14.133	-90.939	-.138	-11.357	-1.2245	-61.226	.83106-001	.29955-003
.900	13.110	-91.056	-.174	-12.745	-1.2244	-54.417	.83106-001	.33718-003
1.000	12.194	-91.174	-.213	-14.124	-1.2242	-48.969	.83106-001	.37486-003
2.000	6.166	-92.341	-.799	-27.148	-1.2219	-24.439	.83112-001	.75640-003
3.000	2.633	-93.497	-1.633	-38.457	-1.2181	-16.242	.83127-001	.11499-002
4.000	.119	-94.637	-2.592	-47.967	-1.2129	-12.129	.83156-001	.15584-002
5.000	-1.837	-95.760	-3.590	-55.892	-1.2062	-9.6492	.83204-001	.19826-002
6.000	-3.441	-96.866	-4.575	-62.533	-1.1980	-7.9870	.83279-001	.24211-002
7.000	-4.802	-97.954	-5.525	-68.168	-1.1886	-6.7920	.83382-001	.28713-002
8.000	-5.986	-99.027	-6.428	-73.021	-1.1779	-5.8894	.83518-001	.33298-002
9.000	-7.033	-100.085	-7.282	-77.267	-1.1660	-5.1821	.83688-001	.37935-002
10.000	-7.974	-101.130	-3.090	-81.034	-1.1529	-4.6118	.83893-001	.42591-002
20.000	-14.268	-111.030	-14.329	-105.584	-.98000	-1.9600	.87870-001	.85150-002
30.000	-18.048	-120.376	-18.773	-120.292	-.78400	-1.0453	.95198-001	.10835-001
40.000	-20.766	-130.019	-27.352	-130.739	-.61250	-.61250	.10530	.91784-002
50.000	-22.985	-140.755	-25.389	-138.622	-.47805	-.38244	.11584	.11824-002
60.000	-25.105	-152.569	-28.049	-144.768	-.37692	-.25128	.12192	-.13371-001
70.000	-27.379	-164.286	-30.429	-149.563	-.30154	-.17231	.11946	-.29852-001
80.000	-29.829	-174.373	-32.572	-153.248	-.24500	-.12250	.10997	-.42077-001
90.000	-32.321	177.947	-34.502	-156.088	-.20206	-.89805-001	.98384-001	-.48017-001
100.000	-34.718	172.565	-36.247	-158.337	-.16897	-.67586-001	.88087-001	-.49304-001
200.000	-49.771	163.785	-47.947	-168.742	-.47115-001	-.94231-002	.59923-001	-.31228-001
300.000	-56.674	161.142	-54.912	-172.433	-.21397-001	-.28530-002	.60827-001	-.30265-001
400.000	-61.314	151.726	-59.881	-174.313	-.12129-001	-.12129-002	.58478-001	-.39421-001
500.000	-65.549	140.147	-63.745	-175.445	-.77901-002	-.62321-003	.48242-001	-.47286-001
600.000	-69.595	130.913	-66.906	-176.200	-.54204-002	-.36136-003	.36788-001	-.48644-001
700.000	-73.242	124.560	-69.579	-176.740	-.39870-002	-.22783-003	.28314-001	-.46588-001
800.000	-76.430	120.026	-71.896	-177.145	-.30549-002	-.15274-003	.22514-001	-.43876-001
900.000	-79.213	116.409	-73.940	-177.461	-.24150-002	-.10733-003	.18322-001	-.41416-001
1000.000	-81.675	113.200	-75.769	-177.714	-.19569-002	-.78275-004	.15027-001	-.39334-001
2000.000	-98.315	84.695	-87.805	-178.855	-.48980-003	-.97961-005	-.27843-002	-.24625-001
3000.000	-109.537	64.036	-94.848	-179.236	-.21774-003	-.29032-005	-.68891-002	-.13681-001
4000.000	-118.252	50.581	-99.845	-179.427	-.12249-003	-.12249-005	-.64166-002	-.76491-002
5000.000	-125.332	41.499	-103.721	-179.542	-.78395-004	-.62716-006	-.52072-002	-.45331-002
6000.000	-131.266	35.050	-106.889	-179.618	-.54442-004	-.36295-006	-.41295-002	-.28559-002
7000.000	-136.356	30.263	-109.566	-179.673	-.39999-004	-.22856-006	-.32958-002	-.18979-002

TRQ DIS - SIG OT H 2 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	189.736	-4.157	-134.533	90.531	438.05	6912.9	-4104.8	-.44284+006
.020	177.643	-8.285	-129.512	91.062	432.90	3415.6	-4104.1	-.22137+006
.030	170.513	-12.358	-124.988	91.593	424.57	2233.1	-4102.8	-.14753+006
.040	165.399	-16.350	-122.488	92.124	413.44	1630.7	-4101.1	-.11059+006
.050	161.376	-20.240	-120.548	92.654	399.96	1261.9	-4098.8	-88418.
.060	158.037	-24.012	-118.961	93.184	384.63	1011.1	-4096.0	-73624.
.070	155.163	-27.651	-117.619	93.714	367.97	828.93	-4092.8	-63048.
.080	152.628	-31.149	-116.456	94.244	350.44	690.61	-4089.0	-55109.
.090	150.350	-34.500	-115.429	94.772	332.50	582.29	-4084.8	-48927.
.100	148.273	-37.703	-114.509	95.301	314.50	495.54	-4080.1	-43975.
.200	133.478	-62.442	-108.417	100.542	169.57	132.76	-4006.8	-21531.
.300	123.843	-78.258	-104.779	105.668	95.909	49.736	-3890.7	-13872.
.400	116.626	-89.596	-102.124	110.631	59.636	22.934	-3739.5	-9932.4
.500	110.839	-98.528	-99.996	115.394	40.124	12.165	-3562.2	-7504.1
.600	105.992	-105.997	-98.194	119.929	28.661	7.1103	-3368.1	-5850.3
.700	101.811	-112.470	-96.616	124.220	21.426	4.4570	-3165.5	-4654.2
.800	98.125	-118.205	-95.200	128.261	16.592	2.9426	-2961.4	-3755.0
.900	94.824	-123.355	-93.911	132.050	13.21[illegible]	2.0208	-2761.3	-3061.3
1.000	91.831	-128.023	-92.724	135.593	[illegible]	1.4305	-2569.1	-2516.4
2.000	71.385	-158.468	-84.244	160.129	2.7359	.79626-001	-1274.4	-460.45
3.000	59.289	-173.577	-79.182	172.304	1.2164	-.26882-001	-750.40	-101.31
4.000	50.973	178.329	-75.864	178.183	.68210	-.41030-001	-517.38	-16.456
5.000	44.782	174.231	-73.545	-179.508	.43437	-.40372-001	-397.51	3.1819
6.000	39.922	172.411	-71.843	-179.352	.29971	-.36896-001	-328.20	3.2728
7.000	35.965	172.033	-70.547	179.466	.21850	-.33160-001	-284.33	-3.2894
8.000	32.652	172.568	-69.527	177.433	.16580	-.29758-001	-254.46	-12.194
9.000	29.819	173.685	-68.704	174.854	.12969	-.26791-001	-232.85	-21.832
10.000	27.356	175.172	-68.023	171.916	.10388	-.24228-001	-216.36	-31.564
20.000	12.693	-165.359	-64.303	134.926	.22079-001	-.10822-001	-132.84	-114.47
30.000	5.251	-147.691	-62.798	82.647	.78504-002	-.58233-002	-67.491	-174.69
40.000	.561	-133.486	-66.134	26.263	.34499-002	-.34227-002	4.9309	-219.44
50.000	-2.680	-122.742	-71.549	-5.450	.17233-002	-.21402-002	84.455	-253.63
60.000	-5.079	-114.973	-76.270	-22.710	.94358-003	-.14073-002	170.31	-281.37
70.000	-6.962	-109.484	-80.226	-33.679	.55460-003	-.96546-003	262.46	-305.77
80.000	-8.508	-105.640	-83.620	-41.405	.34500-003	-.68659-003	361.34	-329.00
90.000	-9.820	-102.954	-86.599	-47.201	.22482-003	-.50345-003	467.51	-352.52
100.000	-10.961	-101.080	-89.260	-51.735	.15228-003	-.37895-003	581.53	77.25
200.000	-17.979	-97.755	-106.894	-71.395	.10615-004	-.52859-004	2211.6	-[illegible]66.28
300.000	-21.886	-99.788	-117.353	-77.778	.21426-005	-.16005-004	4755.5	-1491.5
400.000	-24.629	-102.039	-124.816	-80.941	.68317-006	-.68044-005	8171.9	-2619.3
500.000	-26.746	-104.213	-130.617	-82.826	.28083-006	-.34964-005	12413.	-4226.8
600.000	-28.473	-106.370	-135.363	-84.077	.13569-006	-.20273-005	17414.	-6406.6
700.000	-29.941	-108.547	-139.377	-84.970	.73330-007	-.12782-005	23083.	-9247.0
800.000	-31.230	-110.741	-142.856	-85.641	.43017-007	-.85694-006	29310.	-12814.
900.000	-32.389	-112.929	-145.925	-86.166	.26870-007	-.60218-006	35972.	-17145.
1000.000	-33.448	-115.088	-148.671	-86.587	.17636-007	-.43915-006	42952.	-22252.
2000.000	-41.310	-133.008	-166.754	-88.487	.11036-008	-.54960-007	.11224+006	-.10899+006
3000.000	-46.822	-144.456	-177.337	-89.081	.21803-009	-.16288-007	.15965+006	-.22989+006
4000.000	-51.125	-151.818	-184.844	-89.349	.68993-010	-.68721-008	.18733+006	-.35823+006
5000.000	-54.638	-156.799	-190.665	-89.498	.28261-010	-.35186-008	.20368+006	-.48594+006
6000.000	-57.594	-160.344	-175.420	-89.591	.13629-010	-.20363-008	.21382+006	-.61152+006
7000.000	-60.139	-162.978	-199.439	-89.655	.72567-011	-.12823-008	.22043+006	-.73505+006

BOD MOT - SIG DT H 3 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	201.738	175.859	-149.542	94.126	-1.2250	-4900.0	-.17939+006	-.24865+007
.020	189.646	171.747	-143.470	98.225	-1.2250	-2450.0	-.17726+006	-.12264+007
.030	182.517	167.689	-139.863	102.268	-1.2250	-1633.3	-.17382+006	-.79937+006
.040	177.403	163.711	-137.248	106.232	-1.2250	-1225.0	-.16922+006	-.58126+006
.050	173.382	159.833	-135.165	110.095	-1.2250	-980.00	-.16365+006	-.44730+006
.060	170.044	156.073	-133.410	113.841	-1.2250	-816.66	-.15730+006	-.35597+006
.070	167.172	152.449	-131.877	117.455	-1.2250	-700.00	-.15040+006	-.28947+006
.080	164.638	148.955	-130.504	120.930	-1.2250	-612.50	-.14314+006	-.23888+006
.090	162.361	145.611	-129.250	124.260	-1.2250	-544.44	-.13570+006	-.19923+006
.100	160.286	142.414	-128.090	127.443	-1.2250	-490.00	-.12823+006	-.16746+006
.200	145.503	117.685	-119.328	152.028	-1.2250	-244.99	-67930.	-36076.
.300	135.875	101.853	-113.221	167.718	-1.2249	-163.32	-37209.	-8100.8
.400	128.662	90.498	-108.507	178.929	-1.2249	-122.49	-22125.	-413.64
.500	122.876	81.553	-104.659	-172.269	-1.2248	-97.985	-14081.	1911.5
.600	118.030	74.074	-101.398	-164.933	-1.2247	-81.648	-9425.9	2537.4
.700	113.850	67.592	-98.557	-158.595	-1.2246	-69.979	-6552.6	2568.6
.800	110.164	61.850	-96.032	-152.996	-1.2245	-61.226	-4688.9	2389.5
.900	106.864	56.693	-93.754	-147.981	-1.2244	-54.417	-3433.0	2146.7
1.000	103.871	52.018	-91.679	-143.449	-1.2242	-48.969	-2560.9	1898.5
2.000	83.430	21.462	-77.265	-114.323	-1.2219	-24.439	-249.84	552.71
3.000	71.349	6.132	-68.722	-100.419	-1.2181	-16.242	-41.018	223.03
4.000	63.063	-2.243	-62.258	-93.469	-1.2129	-12.129	-7.0598	116.52
5.000	56.912	-6.816	-58.775	-90.319	-1.2062	-9.6492	-.38906	72.068
6.000	52.101	-9.139	-55.585	-89.4.4	-1.1980	-7.9870	.52940	49.865
7.000	48.195	-10.085	-53.064	-89.880	-1.1886	-6.7920	.10310	37.254
8.000	44.934	-10.173	-51.016	-91.194	-1.1779	-5.8894	-.58312	29.380
9.000	42.154	-9.724	-49.324	-93.032	-1.1660	-5.1821	-1.2444	24.093
10.000	39.342	-8.939	-47.896	-95.188	-1.1529	-4.4118	-1.8141	20.339
20.000	25.440	2.830	-40.685	-119.251	-.98000	-1.9600	-4.1902	7.4380
30.000	18.103	13.366	-38.382	-138.766	-.78400	-1.0453	-4.7284	3.9345
40.000	13.313	22.261	-37.771	-153.361	-.61250	-.61250	-4.9308	2.0665
50.000	9.881	29.930	-37.948	-164.136	-.47805	-.38249	-5.0362	.77330
60.000	7.299	36.554	-38.525	-172.058	-.37692	-.25128	-5.1089	-.25555
70.000	5.298	42.233	-39.413	-177.890	-.30154	-.17231	-5.1734	-1.1458
80.000	3.710	47.052	-40.210	177.806	-.24500	-.12250	-5.2422	-1.9586
90.000	2.429	51.091	-41.160	174.619	-.20206	-.89805-001	-5.3233	-2.7274
100.000	1.377	54.429	-42.131	172.258	-.16897	-.67586-001	-5.4228	-3.4717
200.000	-3.708	63.113	-51.019	167.112	-.47115-001	-.94231-002	-8.3976	-10.673
300.000	-6.139	51.868	-57.601	171.032	-.21397-001	-.28530-002	-16.360	-15.950
400.000	-8.286	35.263	-62.386	176.108	-.12129-001	-.12129-002	-27.491	-15.587
500.000	-10.470	17.762	-65.951	-179.493	-.77901-002	-.62321-003	-37.323	-8.7458
600.000	-12.712	.922	-68.716	-175.359	-.54204-002	-.36136-003	-42.547	2.1492
700.000	-14.982	-14.724	-70.968	-174.517	-.39870-002	-.22783-003	-42.439	13.785
800.000	-17.248	-29.055	-72.897	-173.731	-.30549-002	-.15274-003	-38.095	23.728
900.000	-19.486	-42.112	-74.618	-173.682	-.24150-002	-.10733-003	-31.218	30.846
1000.000	-21.680	-59.000	-76.198	-174.071	-.19569-002	-.78275-004	-23.353	35.004
2000.000	-40.465	-130.780	-87.752	-178.440	-.48980-003	-.97961-005	12.928	14.395
3000.000	-54.503	-169.203	-94.832	-179.216	-.21774-003	-.29032-005	8.5151	1.5065
4000.000	-65.457	168.272	-99.841	-179.433	-.12249-003	-.12249-005	4.2554	-.92789
5000.000	-74.352	153.670	-103.720	-179.547	-.78395-004	-.62716-006	2.1818	-1.1015
6000.000	-81.800	143.503	-106.888	-179.621	-.54442-004	-.36295-006	1.1942	-.89597
7000.000	-88.188	136.040	-109.566	-179.674	-.39999-004	-.22856-006	.69724	-.68011

TRQ DIS - PNT ERROR 4 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	195.757	-4.157	-152.750	90.546	8.9045	141.08	-.41328+006	-.43398+008
.020	183.663	-8.286	-146.729	91.091	8.7997	69.711	-.41320+006	-.21694+008
.030	176.534	-12.358	-143.206	91.637	8.6305	45.580	-.41307+006	-.14458+008
.040	171.419	-16.351	-140.705	92.182	8.4043	33.289	-.41289+006	-.10838+008
.050	167.397	-20.241	-138.765	92.727	8.1303	25.763	-.41266+006	-.86644+007
.060	164.057	-24.013	-137.178	93.271	7.8187	20.646	-.41239+006	-.72145+007
.070	161.184	-27.652	-135.836	93.816	7.4799	16.930	-.41206+006	-.61780+007
.080	158.649	-31.150	-134.673	94.360	7.1237	14.108	-.41168+006	-.53998+007
.090	156.370	-34.502	-133.646	94.903	6.7590	11.899	-.41125+006	-.47939+007
.100	154.294	-37.705	-132.726	95.446	6.3932	10.129	-.41077+006	-.43085+007
.200	139.498	-62.446	-126.634	100.832	3.4471	2.7308	-.40335+006	-.21080+007
.300	129.863	-78.264	-122.995	106.104	1.9497	1.0297	-.39160+006	-.13564+007
.400	122.646	-89.604	-120.340	111.212	1.2124	.48022	-.37628+006	-.96952+006
.500	116.858	-98.538	-118.212	116.120	.81576	.25849	-.35833+006	-.73081+006
.600	112.017	-106.009	-116.409	120.800	.58274	.15388	-.33868+006	-.56812+006
.700	107.830	-112.484	-114.830	125.237	.42567	.98610-001	-.31816+006	-.45040+006
.800	104.144	-118.221	-113.414	129.423	.33742	.66824-001	-.29750+006	-.36109+006
.900	100.843	-123.373	-112.124	133.357	.26873	.47308-001	-.27724+006	-.29361+006
1.000	97.849	-128.043	-110.936	137.046	.21892	.34685-001	-.25778+006	-.24000+006
2.000	77.395	-158.508	-102.441	163.035	.55754-001	.44168-002	-.12671+006	-38648.
3.000	65.285	-173.637	-97.356	176.656	.24866-001	.13132-002	-73675.	-4299.9
4.000	56.952	178.300	-94.008	-176.029	.14004-001	.55469-003	-50117.	3476.7
5.000	50.738	174.132	-91.655	-172.300	.89677-002	.28416-003	-38026.	5129.6
6.000	45.851	172.292	-89.915	-170.740	.62294-002	.16450-003	-31066.	5042.9
7.000	41.860	171.896	-88.576	-170.534	.45776-002	.10361-003	-26693.	4419.3
8.000	38.510	172.413	-87.512	-171.187	.35051-002	.69418-004	-23750.	3643.6
9.000	35.636	173.511	-86.642	-172.394	.27697-002	.48759-004	-21655.	2849.9
10.000	33.127	174.981	-85.914	-173.960	.22436-002	.35547-004	-20091.	2085.8
20.000	17.879	-165.694	-81.701	164.073	.56101-003	.44442-005	-13478.	-3323.5
30.000	9.597	-148.109	-79.042	134.728	.24934-003	.13169-005	-10313.	-6341.7
40.000	4.140	-133.939	-78.393	96.018	.14026-003	.55556-006	-8060.9	-8237.3
50.000	.241	-123.200	-80.628	63.252	.89766-004	.28445-006	-6301.9	-9564.1
60.000	-2.693	-115.419	-83.687	44.185	.62337-004	.16461-006	-5078.4	-10613.
70.000	-4.979	-109.910	-86.483	33.316	.45799-004	.10366-006	-4207.9	-11536.
90.000	-6.879	-106.043	-88.902	26.569	.35065-004	.69445-007	-3594.6	-12408.
90.000	-8.454	-103.334	-91.010	22.037	.27706-004	.48774-007	-3168.4	-13264.
100.000	-9.804	-101.437	-92.875	18.804	.22442-004	.35556-007	-2880.4	-14122.
200.000	-17.642	-97.963	-104.936	7.584	.56104-005	.44445-008	-3257.8	-23156.
300.000	-21.733	-99.930	-111.969	4.709	.24935-005	.13169-008	-5682.0	-32356.
400.000	-24.543	-102.145	-116.987	3.381	.14026-005	.55556-009	-8906.5	-41308.
500.000	-26.692	-104.297	-120.847	2.616	.89767-006	.28445-009	-12748.	-49958.
600.000	-28.436	-106.438	-124.017	2.117	.62338-006	.16461-009	-17203.	-58249.
700.000	-29.915	-108.604	-126.698	1.764	.45799-006	.10366-009	-22260.	-66078.
800.000	-31.210	-110.789	-129.020	1.499	.35065-006	.69446-010	-27860.	-73339.
900.000	-32.373	-112.971	-131.069	1.291	.27706-006	.48774-010	-33907.	-79955.
1000.000	-33.437	-115.124	-132.902	1.123	.22442-006	.35556-010	-40293.	-85885.
2000.000	-41.308	-133.020	-144.969	.367	.56104-007	.44445-011	-.10461+006	-.11209+006
3000.000	-46.822	-144.461	-152.031	.155	.24935-007	.13169-011	-.14880+006	-.10628+006
4000.000	-51.125	-151.820	-157.040	.078	.14026-007	.55556-012	-.17460+006	-93534.
5000.000	-54.638	-156.800	-160.923	.044	.89767-008	.28445-012	-.18984+006	-81358.
6000.000	-57.594	-160.345	-164.094	.027	.62338-008	.16461-012	-.19929+006	-71173.
7000.000	-60.139	-162.978	-166.775	.018	.45799-008	.10366-012	-.20546+006	-62893.

BOD HOT - PNT ERROR 5 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	201.738	-4.141	-161.736	94.141	.00000	100.00	-.88206+007	-.12184+009
.020	189.646	-8.253	-155.666	98.253	.00000	50.000	-.87159+007	-.60088+008
.030	182.517	-12.311	-152.059	102.311	.00000	33.333	-.85467+007	-.39163+008
.040	177.403	-16.289	-149.445	106.289	.00000	25.000	-.83203+007	-.28473+008
.050	173.382	-20.167	-147.361	110.167	.00000	20.000	-.80460+007	-.21908+008
.060	170.044	-23.927	-145.607	113.927	.00000	16.667	-.77339+007	-.17431+008
.070	167.172	-27.556	-144.074	117.556	.00000	14.286	-.73944+007	-.14171+008
.080	164.638	-31.045	-142.700	121.045	.00000	12.500	-.70373+007	-.11691+008
.090	162.361	-34.389	-141.446	124.389	.00000	11.111	-.66712+007	-.97471+007
.100	160.286	-37.586	-140.286	127.586	.00000	10.000	-.63039+007	-.81899+007
.200	145.503	-62.315	-131.524	152.315	.00000	5.0000	-.33373+007	-.17510+007
.300	135.875	-78.147	-125.418	168.147	.00000	3.3333	-.18241+007	-.38324+006
.400	128.662	-89.502	-120.703	179.502	.00000	2.5000	-.10842+007	-9426.0
.500	122.876	-98.447	-116.855	-171.553	.00000	2.0000	-.68868+006	.10227+006
.600	118.030	-105.926	-113.593	-164.074	.00000	1.6667	-.45990+006	.13123+006
.700	113.850	-112.406	-110.752	-157.592	.00000	1.4286	-.31878+006	.13144+006
.800	110.164	-118.150	-108.226	-151.850	.00000	1.2500	-.22732+006	.12163+006
.900	106.864	-123.307	-105.949	-146.693	.00000	1.1111	-.16577+006	.10892+006
1.000	103.871	-127.982	-103.871	-142.018	.00000	1.0000	-.12308+006	96102.
2.000	83.430	-158.538	-89.450	-111.463	.00000	.50000	-10861.	27626.
3.000	71.349	-173.868	-80.889	-96.133	.00000	.33333	-1183.6	11017.
4.000	63.063	177.757	-75.099	-87.755	.00000	.25000	222.79	5687.2
5.000	56.912	173.184	-70.879	-83.175	.00000	.20000	415.86	3479.4
6.000	52.101	170.861	-67.642	-80.838	.00000	.16667	383.81	2385.8
7.000	48.195	169.915	-65.063	-79.876	.00000	.14286	314.87	1770.4
8.000	44.934	169.827	-62.948	-79.769	.00000	.12500	249.37	1389.7
9.000	42.154	170.276	-61.172	-80.200	.00000	.11111	194.79	1136.7
10.000	39.742	171.061	-59.653	-80.968	.00000	.10000+000	150.83	958.90
20.000	25.440	-177.170	-50.984	-92.989	.00000	.50000-001	-18.471	373.70
30.000	18.103	-166.634	-46.529	-105.240	.00000	.33333-001	-55.743	234.60
40.000	13.313	-157.739	-43.463	-118.099	.00000	.25000-001	-70.175	171.43
50.000	9.881	-150.070	-41.241	-132.419	.00000	.20000-001	-77.818	135.16
60.000	7.299	-143.446	-39.790	-148.028	.00000	.16667-001	-82.806	111.69
70.000	5.298	-137.767	-39.107	-163.664	.00000	.14286-001	-86.585	95.379
80.000	3.710	-132.948	-39.069	-177.733	.00000	.12500-001	-89.763	83.553
90.000	2.429	-128.909	-39.451	170.658	.00000	.11111-001	-92.625	74.763
100.000	1.377	-125.571	-40.042	161.529	.00000	.10000-001	-95.310	68.163
200.000	-3.708	-116.887	-45.241	129.543	.00000	.50000-002	-116.40	59.017
300.000	-6.139	-128.132	-47.564	119.156	.00000	.33333-002	-116.39	91.367
400.000	-8.286	-144.737	-49.196	107.975	.00000	.25000-002	-88.957	125.81
500.000	-10.470	-162.238	-51.132	97.287	.00000	.20000-002	-45.696	142.65
600.000	-12.712	-179.078	-53.277	90.278	.00000	.16667-002	-2.2351	138.84
700.000	-14.982	165.276	-55.272	86.868	.00000	.14286-002	31.704	120.64
800.000	-17.248	150.945	-56.976	85.668	.00000	.12500-002	53.333	95.998
900.000	-19.486	137.888	-58.399	85.584	.00000	.11111-002	64.029	70.833
1000.000	-21.680	124.000	-59.590	85.992	.00000	.10000-002	66.671	48.439
2000.000	-40.465	49.220	-66.074	89.591	.00000	.50000-003	14.355	-12.382
3000.000	-54.503	10.797	-69.558	89.980	.00000	.33333-003	1.0582	-5.5491
4000.000	-65.457	-11.728	-72.046	90.006	.00000	.25000-003	-.43377	-2.0895
5000.000	-74.352	-26.330	-73.981	90.005	.00000	.20000-003	-.42493	-.55865
6000.000	-81.800	-36.497	-75.564	90.003	.00000	.16667-003	-.27007	-.39205
7000.000	-88.188	-53.960	-76.902	90.002	.00000	.14286-003	-.18931	-.19631

STABILIZATION LOOP 6 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	149.542	-93.988	-21.607	.003	-.17328+006	-.24870+007	12.033	-.54148-003
.020	143.470	-97.948	-21.607	.005	-.17123+006	-.12272+007	12.033	-.10830-002
.030	139.863	-101.454	-21.607	.008	-.16792+006	-.80060+006	12.033	-.16245-002
.040	137.245	-105.679	-21.607	.010	-.16349+006	-.58286+006	12.033	-.21659-002
.050	135.164	-109.405	-21.607	.013	-.15813+006	-.44924+006	12.033	-.27074-002
.060	133.409	-113.012	-21.607	.015	-.15202+006	-.35820+006	12.033	-.32489-002
.070	131.076	-116.469	-21.607	.018	-.14538+006	-.29196+006	12.033	-.37904-002
.080	130.502	-119.826	-21.607	.021	-.13839+006	-.24159+006	12.033	-.43319-002
.090	129.247	-123.017	-21.607	.023	-.13123+006	-.20212+006	12.033	-.48734-002
.100	128.087	-126.052	-21.607	.026	-.12404+006	-.17050+006	12.033	-.54148-002
.200	119.316	-149.269	-21.607	.052	-65986.	-39309.	12.033	-.10830-001
.300	113.194	-163.583	-21.607	.077	-36398.	-10777.	12.033	-.16245-001
.400	108.458	-173.426	-21.607	.103	-21856.	-2558.5	12.033	-.21659-001
.500	104.584	179.132	-21.607	.129	-14085.	181.76	12.033	-.27074-001
.600	101.289	173.146	-21.607	.155	-9574.3	1124.6	12.033	-.32489-001
.700	98.402	168.145	-21.607	.181	-6776.6	1400.2	12.033	-.37904-001
.800	95.840	163.870	-21.607	.207	-4950.4	1412.4	12.033	-.43319-001
.900	93.513	160.164	-21.607	.232	-3709.9	1321.3	12.033	-.48733-001
1.000	91.382	156.924	-21.607	.258	-2840.1	1194.9	12.033	-.54148-001
2.000	76.186	139.526	-21.606	.521	-410.61	344.03	12.032	-.10829
3.000	66.580	134.847	-21.604	.793	-126.70	123.99	12.032	-.16243
4.000	59.656	134.759	-21.601	1.074	-57.255	55.705	12.030	-.21657
5.000	54.317	136.573	-21.595	1.365	-32.038	28.986	12.029	-.27069
6.000	50.022	139.228	-21.586	1.665	-20.412	16.663	12.027	-.32480
7.000	46.462	142.221	-21.573	1.972	-14.154	10.274	12.025	-.37890
8.000	43.443	145.307	-21.557	2.283	-10.406	6.6626	12.023	-.43298
9.000	40.839	148.357	-21.538	2.595	-7.9823	4.4837	12.020	-.48704
10.000	38.558	151.307	-21.514	2.906	-6.3230	3.0997	12.017	-.54108
20.000	24.772	173.785	-21.083	5.535	-1.4412	.26655-001	11.968	-1.0797
30.000	17.618	-171.796	-20.372	6.493	-.60933	-.17396	11.888	-1.6135
40.000	12.949	-161.009	-19.518	4.981	-.32358	-.18152	11.775	-2.1401
50.000	9.602	-152.299	-18.722	.585	-.19229	-.16463	11.633	-2.6573
60.000	7.082	-145.056	-18.227	-6.259	-.12125	-.14642	11.460	-3.1627
70.000	5.126	-138.987	-18.193	-14.030	-.78515-001	-.13065	11.259	-3.6543
80.000	3.573	-133.909	-18.581	-20.938	-.50836-001	-.11759	11.030	-4.1301
90.000	2.317	-129.690	-19.214	-26.015	-.31897-001	-.10683	10.775	-4.5883
100.000	1.285	-126.224	-19.918	-29.236	-.18380-001	-.97913-001	10.496	-5.0272
200.000	-3.727	-117.115	-23.405	-27.525	.24043-001	-.56688-001	6.7829	-8.1116
300.000	-6.143	-128.265	-23.357	-26.453	.30539-001	-.44571-001	2.7162	-8.7117
400.000	-8.284	-144.828	-23.033	-33.985	.31310-001	-.39984-001	-.38269	-7.5773
500.000	-10.465	-162.304	-23.407	-44.427	.30158-001	-.38178-001	-2.1686	-5.7666
600.000	-12.706	-179.126	-24.295	-52.901	.28097-001	-.37510-001	-2.9018	-3.9997
700.000	-14.975	165.240	-25.269	-58.711	.25548-001	-.37267-001	-2.9875	-2.5795
800.000	-17.241	150.920	-26.140	-62.836	.22741-001	-.37104-001	-2.7501	-1.5506
900.000	-19.478	137.072	-26.880	-66.136	.19829-001	-.36849-001	-2.3908	-.85068
1000.000	-21.672	125.992	-27.513	-69.091	.16924-001	-.36424-001	-2.0155	-.39435
2000.000	-40.456	49.263	-32.117	-96.451	-.26244-002	-.24798-001	-.31286	.21659
3000.000	-54.494	10.878	-36.296	-116.728	-.68970-002	-.13708-001	-.74926-001	.97342-001
4000.000	-65.448	-11.612	-40.014	-129.992	-.64208-002	-.76525-002	-.25419-001	.47036-001
5000.000	-74.342	-26.180	-43.218	-138.959	-.52085-002	-.45334-002	-.10757-001	.25611-001
6000.000	-81.791	-36.314	-45.984	-145.332	-.41299-002	-.28559-002	-.52814-002	.15320-001
7000.000	-88.178	-43.745	-48.397	-150.065	-.32959-002	-.18978-002	-.28818-002	.98415-002

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LADSS*TMPFR(1).IGDATA/NEWJL
K5    .      7.0
K4    .      7.0
TAU7  .      .025
K3    .     46.68
TAU2  .      .01
TAU2P.       .01
TAU3  .     .0005
TAU3P.      .0005
TAU5  .      0.1
TAU6  .      0.80
A     .  100000.0
TAUA  .      .02
LA    .    .00276
RA    .     9.317
RSB   .      1.0
KT    .     19.75
N     .     12.8
JM    .     .0015
JL    .      2.47
D     .     .622
KE    .     .141
KMHD  .     .8595
K2    .     14.0
KF    .      1.0
TAU4  .     .0015
 .01 6 1
SIG DOT - SIG DT H     1
TRQ DIS - SIG DT H     2
BOD MOT - SIG DT H     3
TRQ DIS - PNT ERROR    4
BOD MOT - PNT ERROR    5
STABILIZATION LOOP     6

@XQT L,PROG
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SIG DOT - SIG DT H I LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	52.196	-90.012	.000	-.143	-1.2250	-4900.0	.83105-001	.37360-005
.020	46.176	-90.023	.000	-.287	-1.2250	-2450.0	.83105-001	.74720-005
.030	42.654	-90.035	-.000	-.430	-1.2250	-1633.3	.83105-001	.11208-004
.040	40.155	-90.047	-.000	-.573	-1.2250	-1225.0	.83105-001	.14944-004
.050	38.217	-90.059	-.001	-.716	-1.2250	-980.00	.83105-001	.18680-004
.060	36.633	-90.070	-.001	-.860	-1.2250	-816.66	.83105-001	.22416-004
.070	35.294	-90.082	-.001	-1.003	-1.2250	-700.00	.83105-001	.26153-004
.080	34.135	-90.094	-.001	-1.146	-1.2250	-612.50	.83105-001	.29889-004
.090	33.112	-90.106	-.002	-1.289	-1.2250	-544.44	.83105-001	.33625-004
.100	32.196	-90.117	-.002	-1.433	-1.2250	-490.00	.83105-001	.37361-004
.200	26.176	-90.235	-.009	-2.864	-1.2250	-244.99	.83105-001	.74729-004
.300	22.654	-90.352	-.020	-4.293	-1.2249	-163.32	.83105-001	.11211-003
.400	20.155	-90.470	-.035	-5.718	-1.2249	-122.49	.83105-001	.14951-003
.500	18.216	-90.587	-.054	-7.138	-1.2248	-97.985	.83105-001	.18694-003
.600	16.633	-90.705	-.078	-8.552	-1.2247	-81.648	.83105-001	.22439-003
.700	15.293	-90.822	-.106	-9.958	-1.2246	-69.979	.83105-001	.26189-003
.800	14.133	-90.939	-.138	-11.357	-1.2245	-61.226	.83106-001	.29943-003
.900	13.110	-91.057	-.174	-12.745	-1.2244	-54.417	.83106-001	.33702-003
1.000	12.194	-91.174	-.213	-14.124	-1.2242	-48.969	.83106-001	.37466-003
2.000	6.166	-92.342	-.799	-27.148	-1.2219	-24.439	.83112-001	.75539-003
3.000	2.633	-93.499	-1.632	-38.457	-1.2181	-16.242	.83125-001	.11470-002
4.000	.118	-94.641	-2.591	-47.966	-1.2129	-12.129	.83152-001	.15522-002
5.000	-1.838	-95.767	-3.589	-55.893	-1.2062	-9.6492	.83196-001	.19716-002
6.000	-3.443	-96.877	-4.574	-62.535	-1.1980	-7.9870	.83264-001	.24039-002
7.000	-4.805	-97.970	-5.523	-68.172	-1.1886	-6.7920	.83359-001	.28468-002
8.000	-5.990	-99.048	-6.426	-73.029	-1.1779	-5.8894	.83483-001	.32972-002
9.000	-7.039	-100.112	-7.280	-77.279	-1.1660	-5.1821	.83638-001	.37521-002
10.000	-7.981	-101.162	-8.087	-81.050	-1.1529	-4.6118	.83825-001	.42086-002
20.000	-14.313	-111.075	-14.329	-105.644	-.98000	-1.9600	.87427-001	.84022-002
30.000	-18.158	-120.275	-18.781	-120.374	-.78400	-1.0453	.93982-001	.10865-001
40.000	-20.957	-129.483	-22.369	-130.808	-.61250	-.61250	.10292	.99408-002
50.000	-23.245	-139.390	-25.413	-138.634	-.47805	-.38244	.11235	.38263-002
60.000	-25.376	-150.044	-28.074	-144.694	-.37692	-.25128	.11863	-.77422-002
70.000	-27.575	-160.615	-30.445	-149.427	-.30154	-.17231	.11842	-.21649-001
80.000	-29.890	-169.928	-32.577	-153.104	-.24500	-.12250	.11211	-.33195-001
90.000	-32.237	-177.277	-34.500	-155.969	-.20206	-.89805-001	.10303	-.40043-001
100.000	-34.511	177.371	-36.242	-158.249	-.16897	-.67586-001	.94124-001	-.42756-001
200.000	-49.140	167.448	-47.944	-168.734	-.47115-001	-.94231-002	.66450-001	-.29394-001
300.000	-55.835	164.419	-54.910	-172.430	-.21397-001	-.28530-002	.68786-001	-.29448-001
400.000	-60.284	154.049	-59.880	-174.314	-.12129-001	-.12129-002	.67581-001	-.41677-001
500.000	-64.466	141.077	-63.745	-175.448	-.77901-002	-.62321-003	.55504-001	-.52667-001
600.000	-68.576	130.876	-66.906	-176.202	-.54204-002	-.36136-003	.41353-001	-.54715-001
700.000	-72.303	124.145	-69.579	-176.741	-.39870-002	-.22783-003	.31171-001	-.52135-001
800.000	-75.552	119.502	-71.896	-177.146	-.30549-002	-.15274-003	.24464-001	-.48768-001
900.000	-78.377	115.894	-73.940	-177.461	-.24150-002	-.10733-003	.19764-001	-.45784-001
1000.000	-80.865	112.724	-75.769	-177.714	-.19569-002	-.78275-004	.16145-001	-.43312-001
2000.000	-97.539	84.513	-87.805	-178.855	-.48980-003	-.97961-005	-.31300-002	-.26917-001
3000.000	-109.745	63.815	-94.848	-179.236	-.21774-003	-.29032-005	-.76043-002	-.14957-001
4000.000	-117.442	50.296	-99.845	-179.427	-.12249-003	-.12249-005	-.70865-002	-.83602-002
5000.000	-124.500	41.128	-103.721	-179.542	-.78395-004	-.62716-006	-.57627-002	-.49514-002
6000.000	-130.407	34.601	-106.889	-179.618	-.54442-004	-.36295-006	-.45831-002	-.31169-002
7000.000	-135.465	29.734	-109.566	-179.673	-.39999-004	-.22856-006	-.36710-002	-.20690-002

TRQ DIS - SIG DT H 2 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	179.087	-3.045	-122.774	90.531	345.27	7862.7	-1060.1	-.11437+006
.020	167.020	-6.081	-116.753	91.062	343.31	3908.9	-1059.9	-57174.
.030	159.934	-9.098	-113.230	91.593	340.09	2581.4	-1059.5	-38103.
.040	154.878	-12.087	-110.729	92.124	335.69	1910.8	-1059.1	-28563.
.050	150.928	-15.041	-108.789	92.654	330.19	1503.5	-1058.5	-22836.
.060	147.672	-17.950	-107.203	93.184	323.71	1228.2	-1057.8	-19015.
.070	144.892	-20.809	-105.861	93.714	316.37	1028.7	-1057.0	-16284.
.080	142.456	-23.612	-104.697	94.243	308.31	877.03	-1056.0	-14233.
.090	140.282	-26.354	-103.670	94.772	299.66	757.56	-1054.9	-12436.
.100	138.313	-29.030	-102.750	95.300	290.54	660.92	-1053.7	-11358.
.200	124.497	-51.956	-96.658	100.541	196.26	222.50	-1034.8	-5561.0
.300	115.460	-68.736	-93.021	105.666	127.37	95.739	-1004.8	-3582.8
.400	108.571	-81.406	-90.366	110.628	85.403	47.773	-965.71	-2565.4
.500	102.970	-91.494	-88.238	115.388	59.987	26.576	-919.92	-1938.3
.600	98.238	-99.888	-86.437	119.921	43.985	16.039	-869.78	-1511.3
.700	94.130	-107.095	-84.858	124.209	33.442	10.298	-817.45	-1202.4
.800	90.495	-113.416	-83.443	128.244	26.195	6.9358	-764.74	-970.21
.900	87.229	-119.041	-82.155	132.028	21.029	4.8507	-713.06	-791.10
1.000	84.262	-124.099	-80.968	135.564	17.231	3.4957	-663.42	-650.41
2.000	63.903	-156.302	-72.488	159.958	4.4666	.28653	-329.00	-119.92
3.000	51.817	-171.791	-67.411	171.846	1.9933	.26648-002	-193.59	-27.664
4.000	43.492	-179.752	-64.055	177.317	1.1192	-.47566-001	-133.30	-6.2426
5.000	37.282	176.430	-61.679	179.117	.71318	-.56158-001	-102.21	-1.6637
6.000	32.400	175.106	-59.901	178.670	.49225	-.54734-001	-84.145	-2.1305
7.000	28.423	175.346	-58.510	176.785	.35894	-.50780-001	-72.624	-4.3123
8.000	25.098	176.589	-57.380	173.942	.27241	-.46417-001	-64.692	-7.0952
9.000	22.261	178.479	-56.433	170.425	.21309	-.42281-001	-58.863	-10.063
10.000	19.805	-179.217	-55.615	166.403	.17070	-.38544-001	-54.331	-13.051
20.000	5.796	-152.255	-50.791	102.713	.36288-001	-.17627-001	-28.631	-38.910
30.000	-.530	-131.749	-55.513	25.545	.12903-001	-.95243-002	-5.4357	-58.409
40.000	-4.267	-118.415	-62.562	-7.468	.56705-002	-.56059-002	21.480	-73.664
50.000	-6.856	-109.936	-68.053	-24.277	.28325-002	-.35076-002	52.094	-86.215
60.000	-8.838	-104.507	-72.502	-35.043	.15509-002	-.23073-002	86.305	-97.262
70.000	-10.449	-100.980	-76.267	-42.705	.91157-003	-.15832-002	124.22	-107.65
80.000	-11.810	-98.654	-79.545	-48.481	.56706-003	-.11261-002	166.03	-117.92
90.000	-12.988	-97.103	-82.455	-53.003	.36953-003	-.82576-003	211.95	-128.42
100.000	-14.026	-96.064	-85.074	-56.644	.25029-003	-.62159-003	262.13	-139.36
200.000	-20.589	-94.569	-102.646	-73.263	.17448-004	-.86724-004	1015.6	-290.16
300.000	-24.304	-95.959	-113.105	-78.872	.35218-005	-.26261-004	2234.9	-540.58
400.000	-26.918	-97.477	-120.565	-81.682	.11229-005	-.11164-004	3912.0	-919.04
500.000	-28.937	-98.975	-126.363	-83.367	.46159-006	-.57368-005	6036.1	-1457.5
600.000	-30.584	-100.478	-131.105	-84.490	.22304-006	-.33264-005	8592.8	-2192.4
700.000	-31.980	-102.001	-135.117	-85.293	.12053-006	-.20972-005	11560.	-3160.5
800.000	-33.197	-103.543	-138.594	-85.896	.70707-007	-.14061-005	14911.	-4394.9
900.000	-34.280	-105.094	-141.661	-86.367	.44165-007	-.98804-006	18614.	-5923.5
1000.000	-35.261	-106.642	-144.405	-86.744	.28987-007	-.72055-006	22633.	-7769.0
2000.000	-42.224	-121.816	-167.469	-88.465	.18139-008	-.90178-007	72811.	-45441.
3000.000	-46.978	-131.827	-173.042	-89.040	.35838-009	-.26725-007	.12335+006	-.11340+006
4000.000	-50.767	-140.038	-180.545	-89.317	.11340-009	-.11276-007	.16292+006	-.19844+006
5000.000	-53.945	-146.164	-186.364	-89.475	.46451-010	-.57733-008	.19132+006	-.29043+006
6000.000	-56.680	-150.811	-191.118	-89.575	.22402-010	-.33411-008	.21134+006	-.38436+006
7000.000	-59.075	-154.419	-195.137	-89.643	.12092-010	-.21041-008	.22558+006	-.47814+006

BOD MOT - SIG DT H 3 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	199.294	176.973	-147.097	93.013	-1.2250	-4900.0	-98886.	-.18788+007
.020	187.227	173.955	-141.051	96.016	-1.2250	-2450.0	-98312.	-.93283+006
.030	180.142	170.956	-137.488	99.001	-1.2250	-1633.3	-97370.	-.61468+006
.040	175.087	167.984	-134.932	101.959	-1.2250	-1225.0	-96081.	-.45362+006
.050	171.138	165.047	-132.921	104.882	-1.2250	-980.00	-94470.	-.35551+006
.060	167.883	162.153	-131.250	107.761	-1.2250	-816.66	-92571.	-.28900+006
.070	165.104	159.308	-129.809	110.591	-1.2250	-700.00	-90419.	-.24067+006
.080	162.670	156.519	-127.535	113.367	-1.2250	-612.50	-88054.	-.20381+006
.090	160.497	153.789	-127.386	116.082	-1.2250	-544.44	-85512.	-.17469+006
.100	158.530	151.124	-126.334	118.733	-1.2250	-490.00	-82834.	-.15109+006
.200	144.731	128.253	-118.555	141.460	-1.2250	-244.99	-55040.	-43843.
.300	135.706	111.469	-113.052	159.101	-1.2249	-163.32	-34651.	-13929.
.400	128.824	98.778	-108.669	170.650	-1.2249	-122.49	-22248.	-3663.4
.500	123.228	88.667	-105.012	-179.383	-1.2248	-97.985	-14798.	159.40
.600	118.498	80.251	-101.866	-171.111	-1.2247	-81.648	-10178.	1591.9
.700	114.392	73.025	-99.099	-164.028	-1.2246	-69.979	-7202.6	2061.5
.800	110.758	66.686	-96.625	-157.831	-1.2245	-61.226	-5218.2	2126.1
.900	107.493	61.042	-94.383	-152.331	-1.2244	-54.417	-3855.3	2021.4
1.000	104.526	55.966	-92.333	-147.398	-1.2242	-48.969	-2896.0	1852.2
2.000	84.172	23.492	-78.007	-116.353	-1.2219	-24.439	-293.27	591.96
3.000	72.107	7.492	-69.480	-101.780	-1.2181	-16.242	-50.527	242.25
4.000	63.828	-1.221	-63.721	-94.490	-1.2129	-12.129	-9.9780	127.08
5.000	57.679	-5.997	-59.541	-91.136	-1.2062	-9.6492	-1.5494	78.706
6.000	52.869	-8.457	-56.352	-90.093	-1.1980	-7.9870	-.70312-001	54.480
7.000	48.964	-9.500	-53.831	-90.460	-1.1886	-6.7920	-.30280	40.703
8.000	45.704	-9.661	-51.784	-91.698	-1.1779	-5.8894	-.92380	32.095
9.000	42.924	-9.269	-50.088	-93.477	-1.1660	-5.1821	-1.5686	26.316
10.000	40.512	-8.530	-48.660	-95.586	-1.1529	-4.6118	-2.1411	22.211
20.000	26.212	3.033	-41.419	-119.457	-.98000	-1.9600	-4.6082	8.1125
30.000	18.874	13.501	-39.073	-139.000	-.78400	-1.0453	-5.1778	4.2879
40.000	14.085	22.361	-38.415	-153.724	-.61250	-.61250	-5.3928	2.2491
50.000	10.653	30.009	-38.547	-164.676	-.47805	-.38244	-5.5053	.83761
60.000	8.071	36.618	-39.085	-172.788	-.37692	-.25128	-5.5833	-.28552
70.000	6.069	42.287	-39.836	-178.798	-.30154	-.17231	-5.6529	-1.2575
80.000	4.482	47.098	-40.700	176.738	-.24500	-.12250	-5.7276	-2.1452
90.000	3.200	51.130	-41.620	173.417	-.20206	-.89805-001	-5.8159	-2.9848
100.000	2.149	54.462	-42.565	170.947	-.16897	-.67586-001	-5.9245	-3.7977
200.000	-2.936	63.119	-51.305	165.622	-.47115-001	-.94231-002	-9.1768	-11.666
300.000	-5.367	51.860	-57.838	169.950	-.21397-001	-.28530-002	-17.883	-17.430
400.000	-7.514	35.244	-62.595	175.463	-.12129-001	-.12129-002	-30.052	-17.026
500.000	-9.697	17.733	-66.132	-179.774	-.77901-002	-.62321-003	-40.798	-9.5388
600.000	-11.939	.885	-68.866	-176.365	-.54204-002	-.36136-003	-46.503	2.3792
700.000	-14.209	-14.770	-71.087	-174.337	-.39870-002	-.22783-003	-46.376	15.105
800.000	-16.475	-29.108	-72.985	-173.445	-.30549-002	-.15274-003	-41.617	25.976
900.000	-18.713	-42.173	-74.679	-173.354	-.24150-002	-.10733-003	-34.091	33.757
1000.000	-20.906	-54.069	-76.238	-173.746	-.19569-002	-.78275-004	-25.484	38.298
2000.000	-39.684	-130.924	-87.746	-178.402	-.48980-003	-.97961-005	14.184	15.714
3000.000	-53.710	-169.423	-94.830	-179.214	-.21774-003	-.29032-005	9.3356	1.6148
4000.000	-64.647	167.977	-99.840	-179.434	-.12249-003	-.12249-005	4.6661	-1.0426
5000.000	-73.520	153.299	-103.720	-179.547	-.78395-004	-.62716-006	2.3932	-1.2278
6000.000	-80.941	143.054	-106.888	-179.621	-.54442-004	-.36295-006	1.3105	-.99939
7000.000	-87.297	135.510	-109.566	-179.674	-.39999-004	-.22856-006	.76555	-.76067

TRQ DIS - PNT ERROR 4 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	180.958	-3.045	-136.843	90.545	7.0062	160.47	-66177.	-.695[illegible]+007
.020	168.892	-6.081	-130.821	91.091	6.9664	79.778	-66164.	-.34[illegible]2+007
.030	161.806	-9.098	-127.298	91.636	6.9012	52.687	-66144.	-.23160+007
.040	156.750	-12.088	-124.798	92.181	6.8118	39.003	-66115.	-.17361+007
.050	152.800	-15.041	-122.857	92.726	6.7002	30.692	-66079.	-.13879+007
.060	149.544	-17.950	-121.271	93.270	6.5688	25.074	-66034.	-.11557+007
.070	146.763	-20.809	-119.929	93.814	6.4199	21.005	-65981.	-.98965+006
.080	144.328	-23.612	-118.765	94.358	6.2563	17.911	-65920.	-.86500+006
.090	142.154	-26.354	-117.738	94.901	6.0806	15.474	-65852.	-.76793+006
.100	140.185	-29.031	-116.819	95.444	5.8957	13.503	-65775.	-.69018+006
.200	126.369	-51.957	-110.726	100.828	3.9826	4.5608	-64588.	-.33769+006
.300	117.331	-68.737	-107.089	106.097	2.5848	1.9734	-62706.	-.21730+006
.400	110.442	-81.407	-104.434	111.202	1.7332	.99238	-60255.	-.15533+006
.500	104.842	-91.496	-102.306	116.106	1.2174	.55767	-57382.	-.11710+006
.600	100.109	-99.890	-100.504	120.783	.89275	.34078	-54235.	-91041.
.700	96.001	-107.097	-98.925	125.214	.67880	.22210	-50951.	-72188.
.800	92.366	-113.419	-97.509	129.393	.53176	.15224	-47644.	-58014.
.900	89.100	-119.045	-96.220	133.321	.42694	.10865	-44401.	-47081.
1.000	86.133	-124.103	-95.033	137.001	.34987	.80132-001	-41286.	-38496.
2.000	65.772	-156.310	-86.543	162.831	.90864-001	.10405-001	-20305.	-6268.8
3.000	53.682	-171.802	-81.452	176.151	.40676-001	.31054-002	-11817.	-791.60
4.000	45.352	-179.767	-78.080	-176.957	.22939-001	.13134-002	-8048.5	428.02
5.000	39.135	176.412	-75.684	-173.749	.14698-001	.67327-003	-6115.9	665.57
6.000	34.245	175.084	-73.886	-172.801	.10213-001	.38987-003	-5005.3	623.65
7.000	30.259	175.320	-72.475	-173.298	.75067-002	.24561-003	-4309.4	495.08
8.000	26.922	176.560	-71.327	-174.758	.57487-002	.16458-003	-3842.8	341.60
9.000	24.074	178.447	-70.363	-176.885	.45430-002	.11561-003	-3512.4	184.75
10.000	21.604	-179.252	-69.531	-179.503	.36803-002	.84291-004	-3267.4	32.183
20.000	7.408	-152.319	-64.429	135.333	.92043-003	.10540-004	-2270.6	-1158.2
30.000	.844	-131.831	-66.481	72.548	.40911-003	.31233-005	-1811.7	-1993.2
40.000	-3.129	-118.505	-71.903	42.906	.23013-003	.13177-005	-1461.7	-2655.2
50.000	-5.923	-110.028	-76.224	30.142	.14729-003	.67467-006	-1190.5	-3220.0
60.000	-8.073	-104.597	-79.612	23.206	.10228-003	.39043-006	-986.93	-3731.1
70.000	-9.819	-101.067	-82.395	18.853	.75146-004	.24587-006	-838.52	-4214.0
30.000	-11.286	-98.737	-84.765	15.869	.57534-004	.16472-006	-733.35	-4682.8
90.000	-12.548	-97.181	-86.833	13.700	.45459-004	.11569-006	-661.61	-5145.3
100.000	-13.653	-96.137	-88.672	12.054	.36822-004	.84335-007	-615.75	-5605.6
200.000	-20.480	-94.612	-100.692	5.495	.92055-005	.10542-007	-838.17	-10245.
300.000	-24.254	-95.989	-107.723	3.553	.40913-005	.31235-008	-1573.9	-14894.
400.000	-26.890	-97.500	-112.718	2.616	.23014-005	.13177-008	-2576.8	-19487.
500.000	-28.919	-98.993	-116.593	2.063	.14729-005	.67468-009	-3811.7	-24014.
600.000	-30.572	-100.492	-119.761	1.698	.10228-005	.39044-009	-52[illegible].1	-28460.
700.000	-31.971	-102.014	-122.439	1.438	.75147-006	.24587-009	-6991.3	-32801.
800.000	-33.190	-103.554	-124.759	1.243	.57535-006	.16472-009	-8932.5	-37006.
900.000	-34.275	-105.103	-126.805	1.089	.45459-006	.11569-009	-11090.	-41052.
1000.000	-35.257	-106.650	-128.636	.965	.36822-006	.84335-010	-13445.	-44917.
2000.000	-42.223	-120.819	-140.685	.389	.92055-007	.10542-010	-43096.	-72221.
3000.000	-46.977	-131.829	-147.737	.196	.40913-007	.31235-011	-73008.	-81560.
4000.000	-50.767	-140.039	-152.741	.110	.23014-007	.13177-011	-96428.	-80792.
5000.000	-53.945	-146.164	-156.622	.067	.14729-007	.67468-012	-.11324+006	-75904.
6000.000	-56.680	-150.811	-159.793	.043	.10228-007	.39044-012	-.12509+006	-69872.
7000.000	-59.075	-154.419	-162.473	.029	.75147-008	.24587-012	-.13351+006	-63924.

BOD MOT - PNT ERROR 5 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	199.294	-3.027	-159.294	93.027	.00000	100.00	-.48684+007	-.92060+008
.020	187.227	-6.045	-153.248	96.045	.00000	50.000	-.48402+007	-.45706+008
.030	180.142	-9.044	-149.685	99.044	.00000	33.333	-.47937+007	-.30116+008
.040	175.087	-12.016	-147.128	102.016	.00000	25.000	-.47302+007	-.22222+008
.050	171.138	-14.953	-145.117	104.953	.00000	20.000	-.46508+007	-.17414+008
.060	167.883	-17.847	-143.446	107.847	.00000	16.667	-.45572+007	-.14154+008
.070	165.[illegible]04	-20.692	-142.006	110.692	.00000	14.286	-.44512+007	-.11785+008
.080	162.670	-23.481	-140.732	113.481	.00000	12.500	-.43346+007	-.99778+007
.090	160.497	-26.211	-139.582	116.211	.00000	11.111	-.42093+007	-.85505+007
.100	158.530	-28.876	-138.530	118.876	.00000	10.000	-.40774+007	-.73933+007
.200	144.731	-51.747	-130.751	141.747	.00000	5.0000	-.27076+007	-.21348+007
.300	135.706	-68.531	-125.248	158.531	.00000	3.3333	-.17029+007	-.66973+006
.400	128.824	-81.222	-120.865	171.222	.00000	2.5000	-.10918+007	-.16859+006
.500	123.228	-91.333	-117.208	-178.667	.00000	2.0000	-.72488+006	16871.
.600	118.498	-99.749	-114.061	-170.251	.00000	1.6667	-.49746+006	85466.
.700	114.392	-106.975	-111.294	-163.025	.00000	1.4286	-.35105+006	.10716+006
.800	110.758	-113.314	-108.820	-156.686	.00000	1.2500	-.25350+006	.10925+006
.900	107.493	-118.958	-106.578	-151.043	.00000	1.1111	-.18659+006	.10325+006
1.000	104.526	-124.034	-104.526	-145.967	.00000	1.0000	-.13955+006	94245.
2.000	84.172	-156.508	-90.192	-113.494	.00000	.50000	-12888.	29650.
3.000	72.107	-172.508	-81.648	-97.494	.00000	.33333	-1576.7	11988.
4.000	63.828	178.779	-75.863	-88.778	.00000	.25000	132.44	6213.6
5.000	57.679	174.003	-71.647	-83.995	.00000	.20000	399.91	3806.6
6.000	52.869	171.543	-68.412	-81.524	.00000	.16667	388.24	2611.3
7.000	48.964	170.500	-65.835	-80.466	.00000	.14286	324.26	1937.7
8.000	45.704	170.339	-63.722	-80.289	.00000	.12500	258.91	1520.9
9.000	42.924	170.731	-61.948	-80.663	.00000	.11111	202.99	1243.8
10.000	40.512	171.470	-60.431	-81.389	.00000	.10000+000	157.34	1049.0
20.000	26.212	-176.967	-51.797	-93.189	.00000	.50000-001	-21.637	408.33
30.000	18.874	-166.499	-47.402	-105.212	.00000	.33333-001	-61.523	256.25
40.000	14.085	-157.63	-44.410	-117.616	.00000	.25000-001	-77.020	187.23
50.000	10.653	-149.99	-42.252	-131.134	.00000	.20000-001	-85.250	147.61
60.000	8.071	-143.38	-40.811	-145.642	.00000	.16667-001	-90.636	121.96
70.000	6.069	-137.71	-40.060	-160.174	.00000	.14286-001	-94.727	104.15
80.000	4.482	-132.90	-39.897	-173.470	.00000	.12500-001	-98.176	91.238
90.000	3.200	-128.670	-40.141	175.282	.00000	.11111-001	-101.29	81.641
100.000	2.1[illegible]	-125.538	-40.612	166.216	.00000	.10000-001	-104.21	74.435
200.000	-2.[illegible]36	-116.881	-45.384	133.192	.00000	.50000-002	-127.22	64.489
300.000	-5.367	-128.140	-47.500	122.439	.00000	.33333-002	-127.19	99.877
400.000	-7.514	-144.756	-48.939	110.318	.00000	.25000-002	-97.181	137.54
500.000	-9.697	-162.267	-50.823	98.247	.00000	.20000-002	-49.867	155.94
600.000	-11.934	-179.115	-53.030	90.300	.00000	.16667-002	-2.3448	151.75
700.000	-14.209	165.230	-55.106	86.499	.00000	.14286-002	34.759	131.84
800.000	-16.475	150.892	-56.872	85.198	.00000	.12500-002	58.396	104.88
900.000	-18.713	137.827	-58.336	85.131	.00000	.11111-002	70.076	77.356
1000.000	-20.906	125.931	-59.554	85.596	.00000	.10000-002	72.950	52.866
2000.000	-39.684	49.076	-66.080	89.554	.00000	.50000-003	15.672	-13.587
3000.000	-53.710	10.577	-69.560	89.978	.00000	.33333-003	1.1361	-6.0841
4000.000	-64.647	-12.023	-72.046	90.007	.00000	.25000-003	-.48797	-2.2913
5000.000	-73.520	-26.701	-73.981	90.005	.00000	.20000-003	-.47376	-.94191
6000.000	-80.941	-36.946	-75.564	90.003	.00000	.16667-003	-.32360	-.43027
7000.000	-87.297	-44.490	-76.902	90.002	.00000	.14286-003	-.21176	-.21556

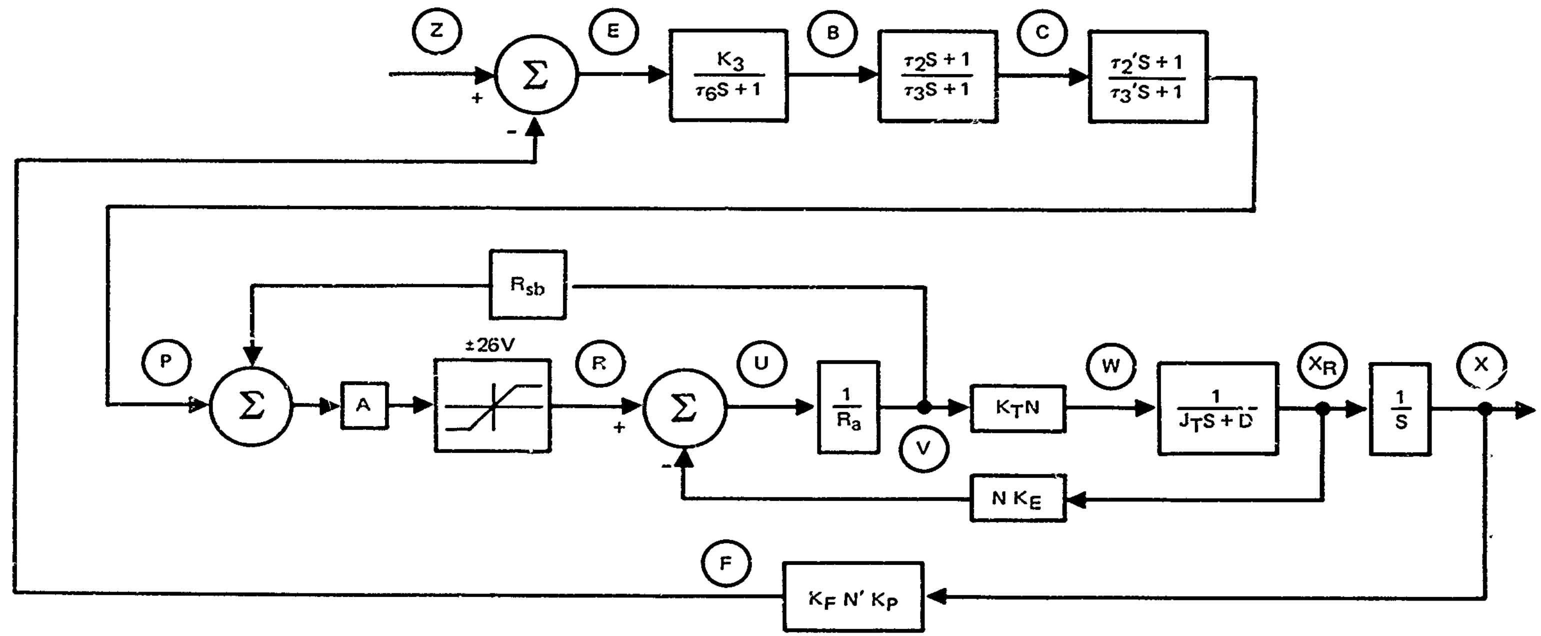
STABILIZATION LOOP 6 LADSS PLATFORM

FREQUENCY RADIANS	LOOP GAIN DB	LOOP GAIN DEGREES	RESPONSE DB	RESPONSE DEGREES	G REAL	G IMAG	H REAL	H IMAG
.010	147.097	-92.875	-21.607	.003	-94272.	-.18790+007	12.033	-.54148-003
.020	141.051	-95.740	-21.607	.005	-93728.	-.93328+006	12.033	-.10330-002
.030	137.488	-98.587	-21.607	.008	-92837.	-.61536+006	12.033	-.16245-002
.040	134.931	-101.407	-21.607	.010	-91615.	-.45451+006	12.033	-.21659-002
.050	132.970	-104.191	-21.607	.013	-90090.	-.35661+006	12.033	-.27074-002
.060	131.248	-106.933	-21.607	.015	-88292.	-.29029+006	12.033	-.32489-002
.070	129.808	-109.625	-21.607	.018	-86255.	-.24214+006	12.033	-.37904-002
.080	128.533	-112.262	-21.607	.021	84015.	-.20545+006	12.033	-.43319-002
.090	127.383	-114.839	-21.607	.023	-81608.	-.17649+006	12.033	-.48734-002
.100	126.331	-117.352	-21.607	.026	-79072.	-.15303+006	12.033	-.54148-002
.200	118.543	-138.701	-21.607	.052	-52749.	-46425.	12.033	-.10830-001
.300	113.025	-153.967	-21.607	.077	-33429.	-16384.	12.033	-.16245-001
.400	108.621	-165.147	-21.607	.103	-21662.	-5786.6	12.033	-.21659-001
.500	104.936	-173.755	-21.607	.129	-14579.	-1628.7	12.033	-.27074-001
.600	101.757	179.323	-21.607	.155	-10174.	92.700	12.033	-.32489-001
.700	98.952	173.578	-21.607	.181	-7322.2	800.82	12.033	-.37904-001
.800	96.433	168.706	-21.607	.206	-5409.0	1060.0	12.033	-.43319-001
.900	94.142	164.514	-21.607	.232	-4084.8	1114.0	12.033	-.48733-001
1.000	92.037	160.873	-21.607	.258	-3144.1	1074.6	12.033	-.54148-001
2.000	76.927	141.557	-21.606	.521	-460.21	358.62	12.032	-.10829
3.000	67.339	136.208	-21.605	.791	-141.44	131.98	12.032	-.16243
4.000	60.420	135.777	-21.601	1.069	-63.595	59.703	12.030	-.21657
5.000	55.084	137.392	-21.595	1.358	-35.444	31.159	12.029	-.27069
6.000	50.790	139.910	-21.587	1.654	-22.515	17.937	12.027	-.32480
7.000	47.231	142.806	-21.576	1.956	-15.578	11.066	12.025	-.37890
8.000	44.213	145.818	-21.561	2.262	-11.435	7.1783	12.023	-.43298
9.000	41.609	148.811	-21.543	2.569	-8.7611	4.8301	12.020	-.48704
10.000	39.329	151.716	-21.522	2.874	-6.9335	3.3378	12.017	-.54108
20.000	25.543	173.989	-21.127	5.490	-1.5752	.23535-001	11.968	-1.0797
30.000	18.390	-171.662	-20.481	6.595	-.66549	-.19168	11.888	-1.6135
40.000	13.720	-160.910	-19.710	5.517	-.35330	-.19900	11.775	-2.1401
50.000	10.373	-152.220	-18.983	1.950	-.20991	-.18022	11.633	-2.6573
60.000	7.854	-144.993	-18.498	-3.734	-.13233	-.16017	11.460	-3.1627
70.000	5.898	-138.733	-18.389	-10.360	-.85677-001	-.14287	11.259	-3.6543
80.000	4.344	-133.863	-18.642	-16.493	-.55458-001	-.12856	11.030	-4.1301
90.000	3.088	-129.651	-19.130	-21.239	-.34781-001	-.11678	10.775	-4.5883
100.000	2.056	-126.190	-19.711	-24.430	-.20025-001	-.10702	10.496	-5.0272
200.000	-2.055	-117.109	-22.774	-23.862	.26283-001	-.61953-001	6.7829	-8.1116
300.000	-5.371	-128.274	-22.519	-23.176	.33370-001	-.48718-001	2.7162	-8.7117
400.000	-7.512	-144.847	-22.004	-31.662	.34207-001	-.43713-001	-.38269	-7.5773
500.000	-9.693	-162.332	-22.325	-43.497	.32941-001	-.41745-001	-2.1686	-5.7666
600.000	-11.933	-179.163	-23.275	-52.918	.30684-001	-.41019-001	-2.9018	-3.9997
700.000	-14.202	165.195	-24.330	-59.126	.27893-001	-.40757-001	-2.9875	-2.5795
800.000	-16.468	150.867	-25.263	-63.360	.24820-001	-.40582-001	-2.7501	-1.5506
900.000	-18.705	137.811	-26.044	-66.651	.21634-001	-.40305-001	-2.3908	-.85068
1000.000	-20.898	125.922	-26.793	-69.557	.18454-001	-.39842-001	-2.0155	-.39435
2000.000	-39.675	49.119	-31.341	-96.633	-.29400-002	-.27124-001	-.31286	.21659
3000.000	-53.700	10.659	-35.505	-116.949	-.76140-002	-.14990-001	-.74926-001	.97342-001
4000.000	-64.638	-11.906	-39.204	-130.286	-.70916-002	-.83641-002	-.25419-001	.47036-001
5000.000	-73.510	-26.552	-42.386	-139.330	-.57643-002	-.49518-002	-.10757-001	.25611-001
6000.000	-80.932	-36.764	-45.126	-145.781	-.45836-002	-.31169-002	-.52814-002	.15320-001
7000.000	-87.288	-44.274	-47.506	-150.594	-.36712-002	-.20690-002	-.28818-002	.98415-002

APPENDIX G
TIME-DOMAIN ANALYSIS

TIME-DOMAIN ANALYSIS DERIVATION

The time-domain analysis was carried out using time integration computer programs. The advantage of using this program is that nonlinearities can very easily be incorporated into the computer model. The approach is straightforward. First the transfer functions are broken down into first order. This is illustrated in figures G-1 and G-2, the slave and track loops respectively. Each of the first order blocks can then be equated to a first order differential equation. These first order differential equations are listed on figures G-1 and G-2. Once the system of first order differential equations has been defined, they are incorporated into a computer program that uses an integration routine for a step by step time integration of a system of first order differential equations.



$E = Z - F$

$\dot{B} = (K_3 \cdot E - B)/\tau_6$

$\dot{C} = (\tau_2 \cdot \dot{B} + B - C)/\tau_3$

$\dot{P} = (\tau_2' \cdot \dot{C} + C - P)/\tau_3'$

$$R = \frac{P \cdot A \cdot R_a + R_{sb} \cdot A \cdot N \cdot K_E \cdot X_R}{R_a + R_{sb} \cdot A}$$

$U = R - N \cdot K_E \cdot X_R$

$V = U/R_a$

$W = K_T \cdot N \cdot V$

$\dot{X}_R = (W - X_R \cdot D)/J_T$

$\dot{X} = X_R$

$F = K_F \cdot N' \cdot K_P \cdot X$

Figure G-1. Time-domain analysis block diagram of slave loop.

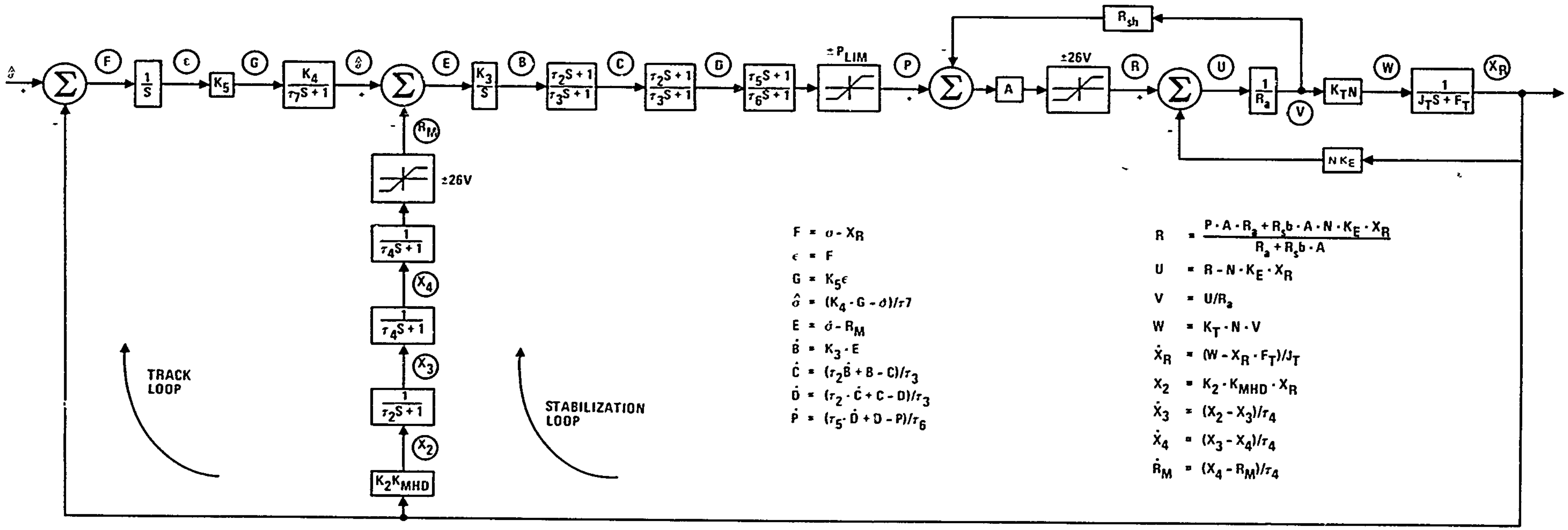


Figure G-2. Time-domain analysis block diagram of track loop.

LADSS* TRKLPTR

```
@FTN,RODS R.MAIN
FTN 9R1  *04/16/80-14:12(10,)
      C**  NAME: LADSS STABILIZED PLATFORM TRACK LOOP TIME RESPONSE
      C**
      C**  USAGE:  THE FOLLOWING CONTROL CARDS WILL EXECUTE THIS PROGRAM
      C**     @XQT LADSS*TRKLPTR.PROG
      C**     @ADD LADSS*TRKLPTR.(APPROPRIATE DATA ELEMENT)
      C**
      C**  PURPOSE:  THIS PROGRAM MODELS (IN THE TIME DOMAIN ) THE TRACK
      C**     LOOP OF THE LADSS GIMBALED PLATFORM BY NUMERICAL INTEGRATION
      C**     OF THE DIFFERENTIAL EQUATIONS THAT MODEL THE SYSTEM.
      C**     THAT IS, IT COMPUTES THE TIME RESPONSE OF THE TRACK LOOP
      C**     TO A GIVEN INPUT SIGNAL.
      C**
      C**  LIMITATIONS: THE MOTOR AMPLIFIER IS MODELED AS A STREIGHT
      C**     GAIN (A), AND THE ARMATURE INDUCTANCE (LA) IS OMITTED.
      C**
      C**  WARNINGS: THIS PROGRAM MAY USE CONSIDERABLE COMPUTER TIME IF THE
      C**     INPUTS STOPT AND DT ARE CHOSEN INCORRECTLY.
      C**
      C**  SUBPROGRAMS REQUIRED:
      C**      EQINT - PERFORMS THE NUMERICAL INREGRATION
      C**
      C**  ARGUMENTS: NONE
      C**
      C**  NOTES:
      C**      1: THIS PROGRAM RUNS ON THE UNIVAC 1110 IN ASCII FORTRAN
      C**         CAU TIME IS APPROXIMATELY  .00038 * (DT/STOPT).
      C**         NUMBER OF PAGES OF OUTPUT IS APPROXIMATELY  .09 * (DP/STOPT).
      C**      2: EACH INPUT VARIABLE IS ON A SEPERATE LINE WITH 7 SPACES
      C**         AVAILABLE AT THE BEGINNING OF THE LINE FOR THE VARIABLE NAME.
      C**      3: OUTPUT IS GENERATED EVERY DP SECONDS OF SIMULATED TIME
      C**      4: THE INPUT SIGNAL (SIGD) IS CHOSEN AS EITHER:
      C**         A) A STEP FUNCTION WHOSE VALUE IS GIVEN BY INPUT STPA
      C**         B) A SINUSOID WHOSE FREQUENCY & AMPLITUDE ARE GIVEN BY
      C**         INPUT VARIABLES SINF AND SINA RESPECTIVELY.
      C**         THE CHOICE IS MADE BY SETTING LOGICAL VARIABLE SIGF PROPERLY
      C**         SIGF = .TRUE. YIELDS A SINUSOID WHILE
      C**         SIGF = .FALSE. YIELDS A STEP FUNCTION.
      C**
      C**  PROGRAMMER/ORGANIZATION: DARYL E. SMITH  CSC DEPT 551
      C**
      C**  ALGORITHM:
      C**      1. READ AND ECHO INPUTS
      C**      2. INITIALIZE CONTROL VARIABLES
      C**      3. DO WHILE T .LE. STOPT
      C**            COMPUTE VALUE OF DIFFERENTIALS
      C**            CALL EQINT
      C**            CHECK FOR OUTPUT
      C**      4. END DO
      C**      5. STOP
      C**
      C**  RECORD OF MODIFICATIONS:
            START EDIT PAGE
```

```
REAL      A                 @ OPEN LOOP AMPLIFIER GAIN  V/V
REAL      B                 @ SEE BLOCK DIAGRAM
REAL      BD                @ DERIVATIVE OF B
REAL      C                 @ SEE BLOCK DIAGRAM
REAL      CD                @ DERIVATIVE OF C
REAL      D                 @ SEE BLOCK DIAGRAM
REAL      DD                @ DERIVATIVE OF D
REAL      DP                @ PRINT INTERVAL
REAL      DT                @ INTEGRATION INTERVAL
REAL      E                 @ OUTPUT OF STAB LOOP SUMMER
REAL      EPS               @ POINTING ERROR  DEG
REAL      EPSD              @ POINTING ERROR RATE  DEG
REAL      F                 @ OUTPUT OF TRACK LOOP SUMMER
REAL      FT                @ TOTAL FRICTION
REAL      G                 @ SEE BLOCK DIAGRAM
INTEGER   HEADER ( 20 )     @ DATA IDENTIFICATION LABEL BUFFER
INTEGER   I                 @ I/O IMPLIED LOOP COUNTER
INTEGER   IPRINT            @ NO. OF DT'S BETWEEN OUTPUTS
REAL      JL                @ LOAD INERTIA  OZ-IN-SEC**2
REAL      JM                @ MOTOR INERTIA  OZ-IN-SEC**2
REAL      J                 @ TOTAL INERTIA  OZ-IN-SEC**2
REAL      K2                @ RATE SENS FILT GAIN  VDC/VRMS
REAL      K3                @ COMPENSATION GAIN  V/V
REAL      K4                @ GUIDANCE SIGNAL FILT GAIN  V/V
REAL      K5                @ SENSOR GAIN  VDC/RAD/SEC
REAL      KE                @ BACK EMF CONSTANT  V/RAD/SEC
REAL      KRMD              @ RATE SENSOR GAIN  VRMS/RAD/SEC
REAL      KT                @ TRQ SENSITIVITY CONST OZ-IN/AMP
REAL      N                 @ GEAR RATIO GIMBAL-TO-MOTOR
INTEGER   NIT               @ LOOP COUNTER (COUNTS NO. OF DT'S)
INTEGER   NODTS             @ TOTAL # OF DT'S TO PERFORM
INTEGER   NSYS              @ NO. OF EQUATIONS IN SYSTEM
REAL      P                 @ OUTPUT OF COMPENSATION BLOCK  V
REAL      PD                @ DERIVATIVE OF P
REAL      PLIM              @ LIMIT ON P
REAL      R                 @ AMPLIFIER OUTPUT
REAL      RA                @ ARMATURE RESISTANCE  OHMS
REAL      RM                @ MEASURED RATE FEEDBACK
REAL      RMD               @ DERIVATIVE OF RM
REAL      RS3               @ CURRENT FEEDBACK CONSTANT  OHMS
REAL      SIGD              @ TRACK LOOP INPUT
REAL      SIGDH             @ ESTIMATED LINE-OF-SIGHT
REAL      SIGDHD            @ DERIVATIVE OF SIGDH
REAL      SIGDHO            @ SIGDH SCALED FOR OUTPUT
REAL      SIGDT             @ TEMP VARIABLE
LOGICAL   SIGF              @ INPUT SIGNAL FLAG
REAL      SIVA              @ AMPLITUDE OF SINUSOID INPUT
REAL      SIVF              @ FREQUENCY OF SISUSOID INPUT
REAL      STOPT             @ STOP TIME
REAL      STPA              @ AMPLITUDE OF STEP INPUT
REAL      T                 @ SIMULATED TIME
REAL      TAU2              @ ALL TAU'S ARE TIME CONSTANTS
REAL      TAU3
REAL      TAU4
REAL      TAU5
REAL      TAU5
REAL      TAU7
```

```
      REAL      U               ! SEE BLOCK DIAGRAM
      REAL      V               ! MOTOR CURRENT OUTPUT  AMPS
      REAL      W               ! MOTOR TORQUE OUTPUT OZ-IN-SEC2
      REAL      X2              ! SEE BLOCK DIAGRAM
      REAL      X3              ! SEE BLOCK DIAGRAM
      REAL      X3D             ! DERIVATIVE OF X3
      REAL      X4              ! SEE BLOCK DIAGRAM
      REAL      X4D             ! DERIVATIVE OF X4
      REAL      XR              ! STAB LOOP OUTPUT
      REAL      XRD             ! DERIVATIVE OF XR
      REAL      Y  (30)         ! OUTPUT OF NUMERICAL INTEGRATION
      REAL      YD  (30)        ! DERIVATIVES INPUT TO NUM INTG
      EQUIVALENCE ( Y (  1 ) , EPS   ) , ( YD (  1 ) , EPSD   )
      EQUIVALENCE ( Y (  2 ) , SIGDH ) , ( YD (  2 ) , SIGDHD )
      EQUIVALENCE ( Y (  3 ) , B     ) , ( YD (  3 ) , BD     )
      EQUIVALENCE ( Y (  4 ) , C     ) , ( YD (  4 ) , CD     )
      EQUIVALENCE ( Y (  5 ) , D     ) , ( YD (  5 ) , DD     )
      EQUIVALENCE ( Y (  6 ) , R     ) , ( YD (  6 ) , RD     )
      EQUIVALENCE ( Y (  7 ) , XR    ) , ( YD (  7 ) , XRD    )
      EQUIVALENCE ( Y (  8 ) , X3    ) , ( YD (  8 ) , X3D    )
      EQUIVALENCE ( Y (  9 ) , X4    ) , ( YD (  9 ) , X4D    )
      EQUIVALENCE ( Y ( 10 ) , RA    ) , ( YD ( 10 ) , RND    )
       START EDIT PAGE
C
C   READ AND ECHO INPUTS.
C
```

```
      READ ( 5,10 ) ( HEADER ( I ) , I=1,20 )
 10   FORMAT ( 20A4 )
      WRITE ( 6,20 ) (HEADER ( I ) , I=1,20 )
 20   FORMAT ( '1',20A4 )
      READ ( 5,30 ) K5,K4,TAU7,K3,TAU2,    $THE FORMAT IS SET UP SO THAT
     &   TAU3,TAU5,TAU6,PLIM,A,RA,KS3,      $ THERE IS ONE INPUT VARIABLE
     &   KT,N,JM,JL,KE,KMHD,K2,TAU4,FT      $ PER CARD, WITH 7 SPACES LEFT
 30   FORMAT ( 7X,F10.0 )                   $ FOR THE VARIABLE NAME
      WRITE ( 6,40 ) K5,K4,TAU7,K3,TAU2,TAU3,TAU5,TAU6,PLIM,
     &   A,RA,KS3,KT,N,JM,JL,KE,KMHD,K2,TAU4,FT
 40   FORMAT ( '0      T R A C K    L O O P',/,6X,'K5    ',F10.4,/,
     &   6X,'K4    ',F10.4,/,6X,'TAU7 ',F10.4,/,6X,'K3    ',F10.4,/,
     &   6X,'TAU2 ',F10.4,/,6X,'TAU3 ',F10.4,/,6X,'TAU5 ',F10.4,/,
     &   6X,'TAU6 ',F10.4,/,6X,'PLIM ',F10.4,/,6X,'A    ',F10.2,/,
     &   6X,'RA   ',F10.4,/,6X,'KS3  ',F10.4,/,6X,'KT   ',F10.4,/,
     &   6X,'N    ',F10.4,/,6X,'JM   ',F10.4,/,6X,'JL   ',F10.4,/,
     &   6X,'KE   ',F10.4,/,6X,'KMHD ',F10.4,/,6X,'K2   ',F10.4,/,
     &   6X,'TAU4 ',F10.4,/,6X,'FT   ',F10.4 )
      JT = N + N + JM + JL
      READ ( 5,30 ) DT,DP,STOPT,SINF,SINA,STPA
      READ ( 5,50 ) SIGF
 50   FORMAT ( 7X,L5 )
      WRITE ( 6,60 ) DT,STOPT,DP
 60   FORMAT ( '0',5X,'INTEGRATION INTERVAL = ',F10.7,/'0     RUN FOR ',
     &   F5.2,' SECONDS, PRINT EVERY ',F6.4,' SECONDS' )
      IF ( SIGF ) THEN
         WRITE ( 6,70 ) SINF , SINA
 70      FORMAT ('0',5X,'INPUT IS A SINUSOID OF FREQUENCY ',
     $      F10.4,' AND AMPLITUDE ',F10.4)
      ELSE
         WRITE ( 6,80 ) STPA
 80      FORMAT ( '0      INPUT IS A STEP FUNCTION OF AMPLITUDE ',
     &      F10.4 )
      END IF
C
C  INITIALIZE CONTROL VARIABLES.
C
      NSYS = 10
      IPRINT = IFIX ( DP / DT + .001 )
      NODTS = IFIX ( STOPT / DT + .001 )
C
C  MAIN LOOP TO PERFORM INTEGRATION  (DO WHILE T .LE. STOPT ).
C
      DO 110 NIT = 1,NODTS
         IF ( SIGF ) THEN
            SIGDI = SINA * COS ( SINF * T )
         ELSE
            SIGDI = STPA
         END IF
         SIGD = SIGDI
         E = SIGD - XR
         EPSD = E
         G = K5 * EPS
         SIGDHD = ( K4 * G - SIGDH ) / TAU7
         RM = AMIN1 ( AMAX1 ( R4,-26.0 ) , 26.0 )
         E = SIGDH - RM
         BD = K3 * E
```

```
      CD = ( TAU2 * BD + B - C ) / TAU5
      DD = ( TAU2 * CD + C - D ) / TAU3
      P = AMIN1 ( AMAX1 ( P,-PLIM ) , PLIM )
      PD = ( TAU5 * DD + D - P ) / TAU6
      R = ( P * A * RA  +  KSE * W * N * KE * XR ) /
     *    ( RA  +  RSE * W )
      R = AMIN1 ( AMAX1 ( R,-26.0 ) , 26.0 )
      U = R  -  N * KE * XR
      V = U / RA
      W = KT * N * V
      XRD = ( W - XR*FT ) / JT
      X2 = K2 * KMHD * XR
      X3D = ( X2 - X3 ) / TAU4
      X4D = ( X3 - X4 ) / TAU4
      RMD = ( X4 - RM ) / TAU4
      CALL EQINT ( DT,NIT,NSYS,YD,Y )
      T = T + DT
C
C   CHECK FOR OUTPUT
C
      IF ( ( MOD ( NIT,IPRINT ) .EQ. 0 ) .OR. ( NIT .LE. 10 ) ) THEN
         P = AMIN1 ( AMAX1 ( P,-PLIM ) ,PLIM )
         RM = AMIN1 ( AMAX1 ( RM,-26.0 ) ,26.0 )
         SIGDHD = SIGDH / ( K2 * KMHD )
         WRITE ( 6,90 ) T,SIGD,EPS,SIGDHO,XR,P,V,W,RM
90       FORMAT ( '0',8X,'TIME',8X,'- SIGD -',7X,'- EPS -',7X,
     *    '- SIGDH -',6X,'- XR -',/,6X,G10.4,4 ( 3X,G12.5 ) ,/,
     *    '0',22X,'- P -',10X,'- V -',8X,'- W -',10X,'- RM -',/,
     *    16X,4 ( 3X,G12.5 ) )
         R = AMIN1 ( AMAX1 ( R,-26.0 ) ,26.0 )
         WRITE ( 6,100 ) T,SIGDH,SIGDHD,E,PD,R,XRD,RMD
100      FORMAT ( '0',12X,'T,SIGDH,SIGDHD,E:',4 ( 2X,G12.5 ) ,/,
     *    13X,'PD,R,XRD,RMD:',3X,4 ( 2X,G12.5 ) )
      END IF
110   CONTINUE
      STOP 999
      END
```

```
@FTN,RODS R.EQINT
FTN 6R1  *04/10/80-14:31-(10,)
      SUBROUTINE EQINT ( DT,              $ INPUT
     &                   NIT,             $ INPUT
     &                   NSYS,            $ INPUT
     &                   YD,              $ INPUT
     &                   Y )              $ OUTPUT
C**
C**  USAGE: CALL EQINT ( DT,NIT,NSYS,YD,Y )
C**
C**  PURPOSE: THIS ROUTINE PERFORMS A NUMERICAL INTEGRATION ON A SYSTEM
C**    OF FIRST-ORDER LINEAR DIFFERENTIAL EQUATIONS.
C**
C**  LIMITATIONS: THE NUMBER OF EQUATIONS IN THE SYSTEM IS LIMITED TO 30
C**    BY THE DIMENSION OF Y & YD.
C**
C**  WARNINGS: NONE
C**
C**  SUBPROGRAMS REQUIRED: NONE
C**
C**  ARGUMENTS:
C**
C**      INPUT:  DT    - REAL*4 INTEGRATION INTERVAL
C**              NIT   - INTEGER  COUNTS NUMBER OF TIMES EQINT IS CALLED.
C**                      USED TO FLAG SWITCH FROM EULER TO ADAMS-BASHFORTH
C**                      INTEGRATION ALGORITHMS.
C**              NSYS  - NO. OF EQUATIONS IN SYSTEM
C**              YD    - DERIVATIVES INPUT TO NUMERICAL INTEGRATION
C**     OUTPUT:  Y     - INTEGRATED OUTPUT FROM NUMERICAL INTEGRATION
C**
C**  NOTES: THE DIFFERENTIAL EQUATIONS MUST BE CALCULATED BEFORE THE
C**    CALL TO EQINT AND THE RESULTS STORED IN ARRAY YD.
C**    THE RESULTS OF THE INTEGRATION ARE CALCULATED BY EQINT
C**    AND STORED IN ARRAY Y. THERE IS A ONE-ONE CORRESPONDENCE
C**    BETWEEN THE ELEMENTS OF Y & YD; Y(1) IS THE RESULT
C**    OF INTEGRATING YD(1).
C**
C**  PROGRAMMER/ORGANIZATION: DARYL E. SMITH  CSC DEPT 551
C**
C**  ALGORITHM: THE METHOD OF INTEGRATION IS THE STANDARD
C**    ADAMS-BASHFORTH. FOR THE FIRST THREE CALLS TO EQINT, EULER'S
C**    METHOD IS USED AND THE RESULTS STORED IN ARRAY ESAV. AFTER THAT
C**    ADAMS BASHFORTH IS USED.
C**
C**  RECORD OF MODIFICATIONS:
       START EDIT PAGE
```

```
      REAL      C (4)  /-9.,37.,-59.,55./  @ ADAMS-BASHFORTH COEFFICIENTS
      REAL      DT                         @ INTEGRATION INTERVAL
      REAL      DT024                      @ DT / 24.0 MULTIPLIER
      REAL      FSAV(30,4) /120*0.0/       @ INTERMEDIATE STORAGE FOR A-B
      INTEGER   I                          @ LOOP COUNTER
      INTEGER   NIT                        @ COUNTS # OF INTEGRATIONS
      INTEGER   NSYS                       @ NO. OF EQUATIONS IN SYSTEM
      REAL      SUM                        @ ADAMS-BASHFORTH SUM
      REAL      Y    (30)                  @ OUTPUT OF NUMERICAL INTEGRATION
      REAL      YD   (30)                  @ DERIVATIVES INPUT TO NUM-INTG
C
      IF ( NIT .LE. 3 ) THEN
         DT024 = DT / 24.0
         DO 10 I=1,NSYS                    @USE EULER'S TO START
            FSAV ( I,1 ) = FSAV ( I,2 )
            FSAV ( I,2 ) = FSAV ( I,3 )
            FSAV ( I,3 ) = FSAV ( I,4 )
            FSAV ( I,4 ) = YD ( I )
            Y ( I ) = Y ( I ) + DT * FSAV ( I,4 )
   10    CONTINUE
      ELSE
         DO 30 I=1,NSYS                    @ USE ADAMS-BASHFORTH
            SUM = 0.0
            FSAV ( I,1 ) = FSAV ( I,2 )
            FSAV ( I,2 ) = FSAV ( I,3 )
            FSAV ( I,3 ) = FSAV ( I,4 )
            FSAV ( I,4 ) = YD ( I )
            SUM = SUM + C ( 1 ) * FSAV ( I,1 )
            SUM = SUM + C ( 2 ) * FSAV ( I,2 )
            SUM = SUM + C ( 3 ) * FSAV ( I,3 )
            SUM = SUM + C ( 4 ) * FSAV ( I,4 )
            Y(I) = Y(I) + DT024 * SUM
   30    CONTINUE
      END IF
      RETURN
      END
```

```
LADSS*IRLLPTR(1).OGDATA/NE.JL
        LADSS PLATFORM OUTER GIMBAL, UNIT STEP INPUT.
        K5     =      2.0
        K4     =      7.0
        TAU7   =      .025
        K6     =     34.72
        TAU2   =      .010
        TAU3   =      .0005
        TAU5   =      0.1
        TAU6   =      0.6
        PLIM   =     20.0
        A      =   100000.0
        RA     =      3.0
        RSG    =      1.0
        KT     =     24.6
        H      =      8.5
        JM     =      .016
        JL     =      3.30
        KE     =      .177
        KMHD   =      .3595
        K2     =     14.0
        TAU4   =      .0015
        FT     =      .706
        DT     =      .00001
        DP     =      .01
        STOPT  =      1.0
        SINE   =      1.0
        SINA   =      1.0
        SIPA   =      1.0
        SIGF   =  FALSE

@XQT R.PROG
```

```
LADSS PLATFORM OUTER GIMBAL, UNIT STEP INPUT.  *

      T R A C K   L O O P
      K3        7.0000
      K4        7.0000
      TAU1      .0250
      K5       54.7200
      TAU2      .0100
      TAU3      .0005
      TAU5      .1000
      TAU6      .5000
      PLIM     20.0000
      A     100000.00
      PA        3.0000
      RSD       1.0000
      KT       24.0000
      N         6.5000
      JA        .0150
      JL        3.3300
      KE        .1770
      KMHD      .0595
      K2       14.0000
      TAU4      .0015
      FE        .7000

      INTEGRATION INTERVAL =    .0000100

      RUN FOR  1.00 SECONDS, PRINT EVERY  .0100 SECONDS

      INPUT IS A STEP FUNCTION OF AMPLITUDE    1.0000

         TIME          - SIGD -         - EPS -        - SIGDH -         - XR -
      .1000-004        1.0000        .10000-004        .00000           .00000

                        - P -            - V -          - W -           - RM -
                       .00000           .00000          .00000           .00000

               F,SIGDH,SIGDHD,E:    1.0000          .00000          .00000          .00000
               PD,R,XRD,KMD:        .00000          .00000          .00000          .00000

         TIME          - SIGD -         - EPS -        - SIGDH -         - XR -
      .2000-004        1.0000        .20000-004      .16269-007         .00000

                        - P -            - V -          - W -           - RM -
                       .0000            .00000          .00000           .00000

               F,SIGDH,SIGDHD,E:    1.0000          .19600-006      .19600-001      .00000
               PD,R,XRD,KMD:        .00000          .00000          .00000          .00000

         TIME          - SIGD -         - EPS -        - SIGDH -         - XR -
      .3000-004        1.0000        .30000-004      .46659-007         .00000

                        - P -            - V -          - W -           - RM -
                      .03026-008        .00000          .00000           .00000

               F,SIGDH,SIGDHD,E:    1.0000          .58792-006      .39192-001      .19600-006
               PD,R,XRD,KMD:        .33026-005      .00000          .00000          .00000
```

```
   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .4000-004       1.0000         .40000-004     .16584-006       .90507-011

                  - P -          - V -          - W -            - RM -
                 .44243-007     .83323-005     .17501-005       .00000

       F,SIGDH,SIGDHD,E:    1.0000         .12736-005     .53776-001     .58792-006
       PD,P,XRD,RMD:        .24590-002     .24907-007     .39276-006     .00000

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .5000-004       1.0000         .50000-004     .17908-006       .47309-010

                  - P -          - V -          - W -            - RM -
                 .11637-006     .44242-007     .93262-005       .00000

       F,SIGDH,SIGDHD,E:    1.0000         .21549-005     .78349-001     .12736-005
       PD,R,XRD,RMD:        .52265-002     .13274-006     .20930-005     .00000

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .6000-004       1.0000         .60000-004     .26858-006       .12806-009

                  - P -          - V -          - W -            - RM -
                 .22168-006     .11635-006     .24530-004       .00000

       F,SIGDH,SIGDHD,E:    1.0000         .32313-005     .97914-001     .21549-005
       PD,R,XRD,RMD:        .86836-002     .34916-006     .55048-005     .00000

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .7000-004       1.0000         .70000-004     .37433-006       .26385-009

                  - P -          - V -          - W -            - RM -
                 .37383-006     .22167-006     .46728-004       .38622-015

       F,SIGDH,SIGDHD,E:    1.0000         .45043-005     .11747         .32318-005
       PD,R,XRD,RMD:        .12041-001     .66521-006     .10487-004     .16853-010

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .8000-004       1.0000         .80000-004     .49632-006       .48333-009

                  - P -          - V -          - W -            - RM -
                 .57660-006     .37382-006     .76801-004       .19280-014

       F,SIGDH,SIGDHD,E:    1.0000         .59722-005     .13702         .45043-005
       PD,R,XRD,RMD:        .17645-001     .11219-005     .17684-004     .85358-010

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .9000-004       1.0000         .90000-004     .63454-006       .81992-009

                  - P -          - V -          - W -            - RM -
                 .83730-006     .57678-006     .12159-003       .56663-014

       F,SIGDH,SIGDHD,E:    1.0000         .76355-005     .15656         .59722-005
       PD,R,XRD,RMD:        .23078-001     .17311-005     .27286-004     .24335-009

   TIME          - SIGD -        - EPS -        - SIGDH -        - XR -
 .1000-003       1.0000         .10000-003     .78900-006       .12902-008
```

```
                 - P -          - V -          - W -          - RM -
               .11610-005     .83726-006     .17658-003     .13948-013

          F,SIGDH,SIGDHD,E:   1.0000         .94946-005     .17609         .76355-005
          PD,R,XRD,RMD:       .29114-001     .25131-005     .39609-004     .56777-009

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .1000-001       1.0000         .99846-002     .71536-002     .51830-002

                 - P -          - V -          - W -          - RM -
               .24706-001     .24676-001     5.2021         .20054-001

          F,SIGDH,SIGDHD,E:   .99463         .66079-001     16.114         .65935-001
          PD,R,XRD,RMD:       2.6703         .61815-001     1.1666         7.1076

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .2000-001       1.0000         .19854-001     .25285-001     .22944-001

                 - P -          - V -          - W -          - RM -
               .49934-001     .49909-001     10.521         .16704

          F,SIGDH,SIGDHD,E:   .97708         .30425         26.735         .13717
          PD,R,XRD,RMD:       2.3051         .18421         2.3574         22.093

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .3000-001       1.0000         .29490-001     .50532-001     .51310-001

                 - P -          - V -          - W -          - RM -
               .68766-001     .68748-001     14.492         .45438

          F,SIGDH,SIGDHD,E:   .94872         .60806         33.473         .15369
          PD,R,XRD,RMD:       1.4322         .28339         3.2442         34.695

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .4000-001       1.0000         .38605-001     .80171-001     .86404-001

                 - P -          - V -          - W -          - RM -
               .78621-001     .78612-001     16.571         .84498

          F,SIGDH,SIGDHD,E:   .91363         .96469         37.467         .11986
          PD,R,XRD,RMD:       .56647         .36577         3.7052         42.531

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .5000-001       1.0000         .47752-001     .11228         .12423

                 - P -          - V -          - W -          - RM -
               .80990-001     .80986-001     17.072         1.2890

          F,SIGDH,SIGDHD,E:   .87581         1.3511         39.549         .62118-001
          PD,R,XRD,RMD:       -.41853-001    .42980         3.8115         45.595

   TIME          - SIGD -       - EPS -        - SIGDH -      - XR -
 .6000-001       1.0000         .56321-001     .14555         .16191

                 - P -          - V -          - W -          - RM -
               .78798-001     .78796-001     16.610         1.7455
```

F,SIGDH,SIGDHD,E:	.33512	1.7514	40.333	.58949-002
PD,R,XRD,RMD:	-.34731	.47973	3.7020	45.289
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.7000-001	1.0000	.64519-001	.17903	.19798
	- P -	- V -	- W -	- RM -
	.74770-001	.74759-001	15.761	2.1892
F,SIGDH,SIGDHD,E:	.80266	2.1549	40.262	-.34224-001
PD,R,XRD,RMD:	-.42665	.52214	3.5057	43.282
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.8000-001	1.0000	.72367-001	.21232	.23202
	- P -	- V -	- W -	- RM -
	.70680-001	.70676-001	14.899	2.6097
F,SIGDH,SIGDHD,E:	.76601	2.5546	39.649	-.54924-001
PD,R,XRD,RMD:	-.37973	.56106	3.3068	40.641
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.9000-001	1.0000	.79684-001	.24489	.26423
	- P -	- V -	- W -	- RM -
	.67295-001	.67272-001	14.165	3.0068
F,SIGDH,SIGDHD,E:	.73581	2.9467	38.704	-.60073-001
PD,R,XRD,RMD:	-.29710	.59936	3.1415	38.654
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.1000+000	1.0000	.87086-001	.27659	.29497
	- P -	- V -	- W -	- RM -
	.64677-001	.64673-001	13.633	3.3643
F,SIGDH,SIGDHD,E:	.70506	3.3282	37.564	-.56090-001
PD,R,XRD,RMD:	-.23161	.63775	3.0127	36.915
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.1100	1.0000	.93987-001	.30729	.32455
	- P -	- V -	- W -	- RM -
	.62560-001	.62555-001	13.137	3.7463
F,SIGDH,SIGDHD,E:	.67547	3.6976	36.313	-.48690-001
PD,R,XRD,RMD:	-.19759	.67591	2.9079	35.541
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.1200	1.0000	.10060	.33692	.35315
	- P -	- V -	- W -	- RM -
	.60657-001	.60632-001	12.781	4.0956
F,SIGDH,SIGDHD,E:	.64086	4.0542	35.005	-.41456-001
PD,R,XRD,RMD:	-.19161	.71317	2.8124	34.356

```
  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1300      1.0000       .10693       .30546        .38079

            - P -        - V -        - W -         - RM -
            .53697-001   .53691-001   12.372        4.4334

       F,SIGDH,SIGDHD,E:  .61923      4.3776        33.675      -.35880-001
       PD,R,XRD,RMD:     -.19304      .74694        2.7162       33.209

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1400      1.0000       .11298       .39289        .40745

            - P -        - V -        - W -         - RM -
            .56664-001   .56656-001   11.944        4.7596

       F,SIGDH,SIGDHD,E:  .59257      4.7276        32.346      -.31996-001
       PD,R,XRD,RMD:     -.20841      .76295        2.6158       32.025

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1500      1.0000       .11378       .41922        .43309

            - P -        - V -        - W -         - RM -
            .54550-001   .54544-001   11.498        5.0737

       F,SIGDH,SIGDHD,E:  .56693      5.0444        31.033      -.29234-001
       PD,R,XRD,RMD:     -.21390      .81518        2.5117       30.790

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1600      1.0000       .12432       .44447        .45768

            - P -        - V -        - W -         - RM -
            .52411-001   .52404-001   11.047        5.3752

       F,SIGDH,SIGDHD,E:  .54235      5.3483        29.747      -.26958-001
       PD,R,XRD,RMD:     -.21321      .84575        2.4066       29.525

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1700      1.0000       .12963       .46856        .48122

            - P -        - V -        - W -         - RM -
            .50305-001   .50295-001   10.603        5.6642

       F,SIGDH,SIGDHD,E:  .51880      5.6394        28.497      -.24745-001
       PD,R,XRD,RMD:     -.20718      .87486        2.3032       28.272

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1800      1.0000       .13470       .49134        .50375

            - P -        - V -        - W -         - RM -
            .48274-001   .48267-001   10.175        5.9407

       F,SIGDH,SIGDHD,E:  .49627      5.9183        27.287      -.22440-001
       PD,R,XRD,RMD:     -.19331      .90266        2.2036       27.051

  TIME      - SIGD -     - EPS -      - SIGDH -     - XR -
 .1900      1.0000       .13956       .51402        .52530
```

	- P -	- V -	- W -	- RM -
	.46340-001	.46333-001	9.7670	6.2353
F,SIGDH,SIGDHD,E:	.47472	6.1852	26.120	-.20047-001
PD,R,XRD,RMD:	-.16892	.72926	2.1557	25.881
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2000	1.0000	.14420	.53526	.54593
	- P -	- V -	- W -	- RM -
	.44499-001	.44491-001	9.3787	6.4564
F,SIGDH,SIGDHD,E:	.45459	6.4407	24.998	-.17692-001
PD,R,XRD,RMD:	-.17942	.95479	2.0182	24.769
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2100	1.0000	.14864	.55558	.56567
	- P -	- V -	- W -	- RM -
	.42743-001	.42735-001	9.0085	6.7007
F,SIGDH,SIGDHD,E:	.43435	6.6653	23.921	-.15481-001
PD,R,XRD,RMD:	-.17172	.97923	1.9320	23.709
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2200	1.0000	.15288	.57502	.58457
	- P -	- V -	- W -	- RM -
	.41064-001	.41056-001	8.6545	6.9327
F,SIGDH,SIGDHD,E:	.41545	6.9192	22.887	-.13476-001
PD,R,XRD,RMD:	-.16438	1.0026	1.8496	22.698
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2300	1.0000	.15695	.59362	.60267
	- P -	- V -	- W -	- RM -
	.39454-001	.39445-001	8.3150	7.1547
F,SIGDH,SIGDHD,E:	.39735	7.1436	21.895	-.11695-001
PD,R,XRD,RMD:	-.15791	1.0250	1.7705	21.728
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2400	1.0000	.16083	.61142	.61998
	- P -	- V -	- W -	- RM -
	.37907-001	.37898-001	7.9890	7.3673
F,SIGDH,SIGDHD,E:	.38003	7.3572	20.945	-.10126-001
PD,R,XRD,RMD:	-.15115	1.0464	1.6946	20.798
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -
.2500	1.0000	.16455	.62844	.63656
	- P -	- V -	- W -	- RM -
	.36422-001	.36413-001	7.6759	7.5707

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           F,SIGDH,SIGDHD,E:    .35540       7.5620      20.035      -.67399-002
           PD,R,XRD,RMD:       -.14554       1.0069      1.6217       19.935

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .2600      1.0000          .16510         .64472        .65242

              - P -           - V -         - W -         - RM -
             .34997-001      .34986-001     7.3754        7.7554

           F,SIGDH,SIGDHD,E:    .34760       7.7579      19.163      -.75108-002
           PD,R,XRD,RMD:       -.13937       1.0865      1.5518       19.047

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .2700      1.0000          .17150         .66029        .66760

              - P -           - V -         - W -         - RM -
             .33631-001      .33621-001     7.0873        7.9517

           F,SIGDH,SIGDHD,E:    .33242       7.9453      18.328      -.64107-002
           PD,R,XRD,RMD:       -.13361       1.1052      1.4647       18.224

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .2800      1.0000          .17475         .67519        .68212

              - P -           - V -         - W -         - RM -
             .32318-001      .32303-001     6.8105        8.1299

           F,SIGDH,SIGDHD,E:    .31790       3.1245      17.530      -.54327-002
           PD,R,XRD,RMD:       -.12582       1.1231      1.4203       17.439

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .2900      1.0000          .17786         .68945        .69600

              - P -           - V -         - W -         - RM -
             .31064-001      .31054-001     6.5462        8.3005

           F,SIGDH,SIGDHD,E:    .30401       8.2959      16.766      -.45532-002
           PD,R,XRD,RMD:       -.12296       1.1403      1.3588       16.683

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .3000      1.0000          .18083         .70305        .70929

              - P -           - V -         - W -         - RM -
             .29865-001      .29855-001     6.2933        8.4636

           F,SIGDH,SIGDHD,E:    .29072       8.4596      16.035      -.37568-002
           PD,R,XRD,RMD:       -.11674       1.1567      1.3000       15.960

  TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
  .3100      1.0000          .18367         .71608        .72200

              - P -           - V -         - W -         - RM -
             .28717-001      .28707-001     6.0513        8.6196

           F,SIGDH,SIGDHD,E:    .27631       8.6166      15.335      -.30458-002
           PD,R,XRD,RMD:       -.11276       1.1724      1.2436       15.268
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   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3200       1.0000        .13637        .72854         .73416

               - P -         - V -        - W -          - RM -
               .27618-001    .27609-001   5.8197         8.7689

         F,SIGDH,SIGDHD,E:   .26545       8.7665         14.666        -.24183-002
         PD,R,XRD,RMD:       -.10733      1.1574         1.1897         14.607

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3300       1.0000        .16599        .74045         .74580

               - P -         - V -        - W -          - RM -
               .26566-001    .26555-001   5.5976         8.9117

         F,SIGDH,SIGDHD,E:   .25421       8.9096         14.025        -.18677-002
         PD,R,XRD,RMD:       -.10533      1.2017         1.1381         13.973

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3400       1.0000        .19147        .75134         .75692

               - P -         - V -        - W -          - RM -
               .25559-001    .25547-001   5.3854         9.0483

         F,SIGDH,SIGDHD,E:   .24537       9.0469         13.412        -.13638-002
         PD,R,XRD,RMD:       -.98274-001  1.2154         1.0886         13.367

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3500       1.0000        .19535        .76274         .76757

               - P -         - V -        - W -          - RM -
               .24594-001    .24582-001   5.1839         9.1790

         F,SIGDH,SIGDHD,E:   .23244       9.1780         12.825        -.96071-003
         PD,R,XRD,RMD:       -.93775-001  1.2235         1.0413         12.786

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3600       1.0000        .17612        .77316         .77775

               - P -         - V -        - W -          - RM -
               .23670-001    .23659-001   4.9972         9.3040

         F,SIGDH,SIGDHD,E:   .22226       9.3034         12.264        -.58973-003
         PD,R,XRD,RMD:       -.90519-001  1.2411         .99599         12.230

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3700       1.0000        .19529        .78312         .78749

               - P -         - V -        - W -          - RM -
               .22786-001    .22774-001   4.8006         9.4235

         F,SIGDH,SIGDHD,E:   .21252       9.4235         11.727        -.26536-003
         PD,R,XRD,RMD:       -.86913-001  1.2531         .95261         11.697

   TIME        - SIGD -      - EPS -      - SIGDH -      - XR -
   .3800       1.0000        .20037        .79264         .79660
```

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                 - P -          - V -          - W -          - RM -
              .21740-001     .21525-001      4.6224          9.5379

        F,SIGDH,SIGDHD,E:    .20521         9.5579         11.214          .16120-004
        PD,R,XRD,RMD:       -.62496-001     1.2646          .91110         11.188

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .3900     1.0000          .20236          .80175          .80571

                 - P -          - V -          - W -          - RM -
              .21130-001     .21118-001      4.4516          9.6472

        F,SIGDH,SIGDHD,E:    .19430         9.6475         10.723          .26417-003
        PD,R,XRD,RMD:       -.79139-001     1.2755          .87136         10.700

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .4000     1.0000          .20426          .81046          .81422

                 - P -          - V -          - W -          - RM -
              .20355-001     .20343-001      4.2883          9.7518

        F,SIGDH,SIGDHD,E:    .18573         9.7523         10.253          .47910-003
        PD,R,XRD,RMD:       -.74656-001     1.2860          .83337         10.234

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .4100     1.0000          .20607          .81879          .82237

                 - P -          - V -          - W -          - RM -
              .19614-001     .19602-001      4.1320          9.8518

        F,SIGDH,SIGDHD,E:    .17764         9.8525          9.8039         .66149-003
        PD,R,XRD,RMD:       -.74077-001     1.2960          .79700          9.7870

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .4200     1.0000          .20731          .82675          .83016

                 - P -          - V -          - W -          - RM -
              .18905-001     .18892-001      3.9825          9.9475

        F,SIGDH,SIGDHD,E:    .16985         9.9483          9.3743         .81789-003
        PD,R,XRD,RMD:       -.70107-001     1.3056          .76220          9.3602

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .4300     1.0000          .20947          .83436          .83761

                 - P -          - V -          - W -          - RM -
              .18226-001     .18213-001      3.8394         10.039

        F,SIGDH,SIGDHD,E:    .16240        10.040           8.9634         .95010-003
        PD,R,XRD,RMD:       -.66573-001     1.3148          .72891          8.9513

 TIME      - SIGD -        - EPS -        - SIGDH -        - XR -
 .4400     1.0000          .21106          .84164          .84474

                 - P -          - V -          - W -          - RM -
              .17577-001     .17564-001      3.7025         10.126
```

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         F,SIGDH,SIGDHD,E:     .15527        10.120       8.5704        .10519-002
         PD,R,XRD,RMD:        -.63644-001    1.3230        .69707       8.5603

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4500          1.0000          .21257         .84860        .85155

                - P -          - V -          - W -          - RM -
               .16956-001     .16943-001     3.5716        10.210

         F,SIGDH,SIGDHD,E:     .14646        10.211       8.1946        .11535-002
         PD,R,XRD,RMD:        -.60904-001    1.3320        .66660       8.1867

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4600          1.0000          .21402         .85526        .85806

                - P -          - V -          - W -          - RM -
               .16361-001     .16347-001     3.4463        10.290

         F,SIGDH,SIGDHD,E:     .14174        10.291       7.8352        .12286-002
         PD,R,XRD,RMD:        -.57716-001    1.3400        .63745       7.8287

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4700          1.0000          .21541         .86162        .86429

                - P -          - V -          - W -          - RM -
               .15793-001     .15780-001     3.3264        10.367

         F,SIGDH,SIGDHD,E:     .13571        10.363       7.4915        .12877-002
         PD,R,XRD,RMD:        -.57757-001    1.3477        .60957       7.4862

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4799          1.0000          .21674         .86770        .87025

                - P -          - V -          - W -          - RM -
               .15249-001     .15236-001     3.2118        10.440

         F,SIGDH,SIGDHD,E:     .12975        10.441       7.1628        .13355-002
         PD,R,XRD,RMD:        -.52177-001    1.3550        .58291       7.1583

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4899          1.0000          .21801         .87352        .87595

                - P -          - V -          - W -          - RM -
               .14729-001     .14716-001     3.1022        10.510

         F,SIGDH,SIGDHD,E:     .12406        10.511       6.8485        .13709-002
         PD,R,XRD,RMD:        -.51755-001    1.3620        .55740       6.8456

  TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
 .4999          1.0000          .21922         .87905        .88140

                - P -          - V -          - W -          - RM -
               .14232-001     .14219-001     2.9973        10.577

         F,SIGDH,SIGDHD,E:     .11861        10.576       6.5480        .13962-002
         PD,R,XRD,RMD:        -.49672-001    1.3687        .53299       6.5460
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TIME .5099	- SIGD - 1.0000	- EPS - .22335	- SIGDH - .88440	- XR - .88660	
	- P - .13756-001	- V - .13743-001	- w - 2.6969	- RM - 10.641	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.11340 -.47249-001	10.642 1.3751	6.2606 .50965	.14123-002 6.2595
TIME .5199	- SIGD - 1.0000	- EPS - .22146	- SIGDH - .88948	- XR - .89158	
	- P - .13301-001	- V - .13287-001	- W - 2.5010	- RM - 10.702	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.10842 -.44838-001	10.703 1.3812	5.9858 .48733	.14206-002 5.9856
TIME .5299	- SIGD - 1.0000	- EPS - .22254	- SIGDH - .89434	- XR - .89635	
	- P - .12865-001	- V - .12852-001	- w - 2.7092	- RM - 10.760	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.10356 -.42430-001	10.762 1.3871	5.7230 .46597	.14215-002 5.7235
TIME .5399	- SIGD - 1.0000	- EPS - .22356	- SIGDH - .89898	- XR - .90090	
	- P - .12449-001	- V - .12436-001	- W - 2.6214	- RM - 10.816	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.99106-001 -.40136-001	10.817 1.3927	5.4718 .44556	.14170-002 5.4728
TIME .5499	- SIGD - 1.0000	- EPS - .22452	- SIGDH - .90343	- XR - .90525	
	- P - .12051-001	- V - .12037-001	- W - 2.5375	- RM - 10.870	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.94752-001 -.39066-001	10.871 1.3981	5.2315 .42603	.14066-002 5.2327
TIME .5599	- SIGD - 1.0000	- EPS - .22545	- SIGDH - .90767	- XR - .90941	
	- P - .11670-001	- V - .11657-001	- W - 2.4572	- RM - 10.921	
F,SIGDH,SIGDHD,E: PD,R,XRD,RMD:		.90590-001 -.37466-001	10.922 1.4032	5.0018 .40736	.13936-002 5.0040
TIME .5699	- SIGD - 1.0000	- EPS - .22633	- SIGDH - .91173	- XR - .91339	

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                 - P -          - V -         - W -          - RM -
               .11305-001     .11293-001     2.3805         10.759

          F,SIGDH,SIGDHD,E:   .36610-001     10.971         4.7622        .13764-002
          PD,R,XRD,RMD:      -.34446-001     1.4081         .33951        4.7845

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .5799        1.0000         .22718         .91561         .91720

                 - P -          - V -         - W -          - RM -
               .10958-001     .10944-001     2.3070         11.016

          F,SIGDH,SIGDHD,E:   .82805-001     11.016         4.5722        .13540-002
          PD,R,XRD,RMD:      -.34511-001     1.4126         .37241        4.5752

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .5899        1.0000         .22799         .91932         .92084

                 - P -          - V -         - W -          - RM -
               .10625-001     .10611-001     2.2368         11.061

          F,SIGDH,SIGDHD,E:   .79157-001     11.062         4.3714        .13297-002
          PD,R,XRD,RMD:      -.34562-001     1.4172         .35609        4.3741

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .5999        1.0000         .22876         .92287         .92432

                 - P -          - V -         - W -          - RM -
               .10306-001     .10292-001     2.1697         11.104

          F,SIGDH,SIGDHD,E:   .75656-001     11.105         4.1794        .13034-002
          PD,R,XRD,RMD:      -.32330-001     1.4215         .34046        4.1875

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .6099        1.0000         .22950         .92626         .92764

                 - P -          - V -         - W -          - RM -
               .10002-001     .99879-002     2.1055         11.144

          F,SIGDH,SIGDHD,E:   .72362-001     11.146         3.9959        .12759-002
          PD,R,XRD,RMD:      -.28116-001     1.4256         .32552        3.9995

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .6199        1.0000         .23021         .92950         .93082

                 - P -          - V -         - W -          - RM -
               .97104-002     .96964-002     2.0440         11.183

          F,SIGDH,SIGDHD,E:   .69183-001     11.185         3.8204        .12457-002
          PD,R,XRD,RMD:      -.28442-001     1.4295         .31123        3.8236

   TIME        - SIGD -       - EPS -       - SIGDH -       - XR -
  .6299        1.0000         .23088         .93260         .93386

                 - P -          - V -         - W -          - RM -
               .94319-002     .94178-002     1.9853         11.221
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F,SIGDH,SIGDHD,E:	.66143-001	11.222	3.6526	.12155-002	
PD,R,XRD,RMD:	-.26542-001	1.4332	.29757	3.6558	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6399	1.0000	.23155	.93557	.93677	
	- P -	- V -	- W -	- RM -	
	.91664-002	.91523-002	1.9293	11.256	
F,SIGDH,SIGDHD,E:	.63237-001	11.256	3.4921	.11647-002	
PD,R,XRD,RMD:	-.25716-001	1.4363	.28455	3.4951	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6499	1.0000	.23215	.93840	.93954	
	- P -	- V -	- W -	- RM -	
	.89117-002	.88975-002	1.8756	11.291	
F,SIGDH,SIGDHD,E:	.60458-001	11.292	3.3387	.11537-002	
PD,R,XRD,RMD:	-.22330-001	1.4402	.27206	3.3422	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6599	1.0000	.23274	.94111	.94220	
	- P -	- V -	- W -	- RM -	
	.86664-002	.86542-002	1.8243	11.323	
F,SIGDH,SIGDHD,E:	.57601-001	11.324	3.1921	.11195-002	
PD,R,XRD,RMD:	-.27599-001	1.4435	.26012	3.1954	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6699	1.0000	.23330	.94370	.94474	
	- P -	- V -	- W -	- RM -	
	.84357-002	.84214-002	1.7752	11.354	
F,SIGDH,SIGDHD,E:	.55261-001	11.353	3.0519	.10881-002	
PD,R,XRD,RMD:	-.19647-001	1.4466	.24871	3.0557	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6799	1.0000	.23384	.94617	.94717	
	- P -	- V -	- W -	- RM -	
	.82129-002	.81967-002	1.7283	11.384	
F,SIGDH,SIGDHD,E:	.52833-001	11.385	2.9179	.10531-002	
PD,R,XRD,RMD:	-.25916-001	1.4496	.23779	2.9213	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6899	1.0000	.23436	.94854	.94949	
	- P -	- V -	- W -	- RM -	
	.80003-002	.79660-002	1.6834	11.413	
F,SIGDH,SIGDHD,E:	.50512-001	11.414	2.7397	.10217-002	
PD,R,XRD,RMD:	-.17653-001	1.4525	.22736	2.7939	

TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6999	1.0000	.23485	.95080	.95171	
	- P -	- V -	- W -	- RM -	
	.77963-002	.77820-002	1.6404	11.440	
F,SIGDH,SIGDHD,E:		.48294-001	11.441	2.6672	.98670-003
PD,R,XRD,RMD:		-.25079-001	1.4552	.21736	2.6704
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7099	1.0000	.23532	.95296	.95383	
	- P -	- V -	- W -	- RM -	
	.76024-002	.75880-002	1.5995	11.466	
F,SIGDH,SIGDHD,E:		.46171-001	11.467	2.5501	.95594-003
PD,R,XRD,RMD:		-.19082-001	1.4573	.20784	2.5540
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7199	1.0000	.23577	.95503	.95586	
	- P -	- V -	- W -	- RM -	
	.74150-002	.74006-002	1.5600	11.491	
F,SIGDH,SIGDHD,E:		.44142-001	11.492	2.4382	.92328-003
PD,R,XRD,RMD:		-.18338-001	1.4603	.19866	2.4419
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7299	1.0000	.23620	.95701	.95780	
	- P -	- V -	- W -	- RM -	
	.72371-002	.72227-002	1.5225	11.515	
F,SIGDH,SIGDHD,E:		.42203-001	11.516	2.3311	.89180-003
PD,R,XRD,RMD:		-.17785-001	1.4627	.18993	2.3347
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7399	1.0000	.23661	.95889	.95965	
	- P -	- V -	- W -	- RM -	
	.70686-002	.70541-002	1.4870	11.538	
F,SIGDH,SIGDHD,E:		.40349-001	11.533	2.2287	.86260-003
PD,R,XRD,RMD:		-.16401-001	1.4650	.18166	2.2332
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7499	1.0000	.23701	.96070	.96142	
	- P -	- V -	- W -	- RM -	
	.69049-002	.68905-002	1.4523	11.559	
F,SIGDH,SIGDHD,E:		.38577-001	11.560	2.1309	.82982-003
PD,R,XRD,RMD:		-.22240-001	1.4671	.17364	2.1338
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7599	1.0000	.23738	.96243	.96312	

```
               - P -          - V -        - W -        - RX -
             .67506-002     .67361-002    1.4200       11.580

        F,SIGDH,SIGDHD,E:  .35682-001    11.581       2.0373       .60192-003
        PD,R,XRD,RMD:     -.17735-001    1.4692       .16607       2.0415

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .7699       1.0000         .23774       .96408       .96474

               - P -          - V -        - W -        - RM -
             .66005-002     .65859-002    1.3883       11.600

        F,SIGDH,SIGDHD,E:  .35263-001    11.601       1.9479       .77236-003
        PD,R,XRD,RMD:     -.12376-001    1.4712       .15371       1.9511

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .7799       1.0000         .23609       .96566       .96629

               - P -          - V -        - W -        - RM -
             .64591-002     .64445-002    1.3585       11.619

        F,SIGDH,SIGDHD,E:  .33714-001    11.620       1.8624       .74470-003
        PD,R,XRD,RMD:     -.11046-001    1.4731       .15177       1.8655

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .7899       1.0000         .23442       .96716       .96777

               - P -          - V -        - W -        - RM -
             .63227-002     .63080-002    1.3297       11.637

        F,SIGDH,SIGDHD,E:  .32234-001    11.636       1.7607       .71645-003
        PD,R,XRD,RMD:     -.10761-001    1.4749       .14508       1.7833

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .7999       1.0000         .23673       .96861       .96918

               - P -          - V -        - W -        - RM -
             .61936-002     .61790-002    1.3025       11.655

        F,SIGDH,SIGDHD,E:  .30619-001    11.655       1.7025       .68891-003
        PD,R,XRD,RMD:     -.19303-001    1.4767       .13875       1.7048

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .8099       1.0000         .23903       .96999       .97054

               - P -          - V -        - W -        - RM -
             .60657-002     .60540-002    1.2762       11.671

        F,SIGDH,SIGDHD,E:  .29465-001    11.672       1.6279       .66411-003
        PD,R,XRD,RMD:     -.10870-001    1.4783       .13263       1.6311

  TIME       - SIGD -       - EPS -      - SIGDH -     - XR -
 .8199       1.0000         .23932       .97130       .97183

               - P -          - V -        - W -        - RM -
             .59499-002     .59352-002    1.2511       11.667
```

```
         F,SIGDH,SIGDHD,E:     .2[illegible]172-001   11.[illegible]      1.5565       .63848-003
         PD,R,XRD,RMD:        -.10259-001    1.477[illegible]      .12030      1.5600

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8299        1.0000          .23959        .97256          .97507

                - P -           - V -         - W -           - RM -
                .58373-002      .55227-002    1.2274          11.702

         F,SIGDH,SIGDHD,E:     .26935-001     11.703      1.4681       .61262-003
         PD,R,XRD,RMD:        -.17977-001     1.4814      .12128      1.4506

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8399        1.0000          .23986        .97377          .97425

                - P -           - V -         - W -           - RM -
                .57282-002      .57135-002    1.2044          11.717

         F,SIGDH,SIGDHD,E:     .25755-001     11.717      1.4229       .58937-003
         PD,R,XRD,RMD:        -.78472-002     1.4829      .11593      1.4272

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8499        1.0000          .24511        .97492          .97538

                - P -           - V -         - W -           - RM -
                .56260-002      .56112-002    1.1828          11.731

         F,SIGDH,SIGDHD,E:     .24625-001     11.731      1.3605       .56732-003
         PD,R,XRD,RMD:        -.83982-002     1.4843      .11091      1.3633

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8399        1.0000          .24035        .97602          .97646

                - P -           - V -         - W -           - RM -
                .55253-002      .55110-002    1.1617          11.744

         F,SIGDH,SIGDHD,E:     .23543-001     11.744      1.3008       .54407-003
         PD,R,XRD,RMD:        -.70597-002     1.4856      .10600      1.3041

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8699        1.0000          .24058        .97707          .97749

                - P -           - V -         - W -           - RM -
                .54316-002      .54168-002    1.1419          11.757

         F,SIGDH,SIGDHD,E:     .22510-001     11.757      1.2439       .52333-003
         PD,R,XRD,RMD:        -.75406-002     1.4869      .10138      1.2485

   TIME         - SIGD -        - EPS -       - SIGDH -       - XR -
   .8799        1.0000          .24079        .97808          .97848

                - P -           - V -         - W -           - RM -
                .53386-002      .53239-002    1.1223          11.769

         F,SIGDH,SIGDHD,E:     .21522-001     11.769      1.1693       .49961-003
         PD,R,XRD,RMD:        -.17571-001     1.4681      .96826-001   1.1920
```

TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.8899	1.0000	.24100	.97904	.97942	
	- P -	- V -	- W -	- RM -	
	.52553-002	.52384-002	1.1043	11.780	
F,SIGDH,SIGDHD,E:		.20579-001	11.781	1.1372	.48101-003
PD,R,XRD,RMD:		-.60376-002	1.4893	.92656-001	1.1413
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.8999	1.0000	.24120	.97996	.98032	
	- P -	- V -	- W -	- RM -	
	.51723-002	.51575-002	1.0872	11.791	
F,SIGDH,SIGDHD,E:		.19576-001	11.792	1.0874	.46480-003
PD,R,XRD,RMD:		-.70755-002	1.4904	.88665-001	1.0928
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.9099	1.0000	.24140	.98084	.98119	
	- P -	- V -	- W -	- RM -	
	.50925-002	.50777-002	1.0704	11.802	
F,SIGDH,SIGDHD,E:		.18814-001	11.802	1.0398	.44584-003
PD,R,XRD,RMD:		-.58675-002	1.4914	.84752-001	1.0451
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.9199	1.0000	.24158	.98168	.98201	
	- P -	- V -	- W -	- RM -	
	.50157-002	.50008-002	1.0542	11.812	
F,SIGDH,SIGDHD,E:		.17989-001	11.813	.99426	.42558-003
PD,R,XRD,RMD:		-.48474-002	1.4924	.80984-001	1.0008
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.9299	1.0000	.24175	.98248	.98280	
	- P -	- V -	- W -	- RM -	
	.49415-002	.49264-002	1.0385	11.822	
F,SIGDH,SIGDHD,E:		.17201-001	11.822	.95071	.40603-003
PD,R,XRD,RMD:		-.30699-002	1.4934	.77341-001	.95352
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.9399	1.0000	.24192	.98325	.98355	
	- P -	- V -	- W -	- RM -	
	.48751-002	.48602-002	1.0245	11.831	
F,SIGDH,SIGDHD,E:		.16447-001	11.831	.90911	.39160-003
PD,R,XRD,RMD:		-.53423-002	1.4943	.74088-001	.91529
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.9499	1.0000	.24208	.98398	.98427	

```
              - P -           - V -          - W -            - RM -
            .46035-002      .47937-002      1.0105           11.840

          F,SIGDH,SIGDHD,E:   .15727-001      11.840           .86924          .37444-003
          PD,R,XRD,RMD:      -.14126-001      1.4952           .70831-001      .87261

     TIME        - SIGD -         - EPS -         - SIGDH -         - XR -
     .9599       1.0000           .24223          .96465            .98496

              - P -           - V -          - W -            - RM -
            .47408-002      .47260-002      .99623           11.848

          F,SIGDH,SIGDHD,E:   .15033-001      11.849           .83133          .35572-003
          PD,R,XRD,RMD:      -.78242-002      1.4961           .67515-001      .83431

     TIME        - SIGD -         - EPS -         - SIGDH -         - XR -
     .9699       1.0000           .24233          .96535            .98562

              - P -           - V -          - W -            - RM -
            .46801-002      .46652-002      .98341           11.856

          F,SIGDH,SIGDHD,E:   .14380-001      11.857           .79502          .34010-003
          PD,R,XRD,RMD:      -.36635-002      1.4969           .64535-001      .79854

     TIME        - SIGD -         - EPS -         - SIGDH -         - XR -
     .9799       1.0000           .24252          .96599            .98625

              - P -           - V -          - W -            - RM -
            .46224-002      .46075-002      .97125           11.864

          F,SIGDH,SIGDHD,E:   .13750-001      11.864           .76025          .32651-003
          PD,R,XRD,RMD:      -.79668-002      1.4976           .61706-001      .76278

     TIME        - SIGD -         - EPS -         - SIGDH -         - XR -
     .9899       1.0000           .24265          .96661            .98685

              - P -           - V -          - W -            - RM -
            .45729-002      .45580-002      .96084           11.872

          F,SIGDH,SIGDHD,E:   .13149-001      11.872           .72685          .32032-003
          PD,R,XRD,RMD:      -.95526-002      1.4984           .59272-001      .73179

     TIME        - SIGD -         - EPS -         - SIGDH -         - XR -
     .9999       1.0000           .24276          .96719            .98743

              - P -           - V -          - W -            - RM -
            .45207-002      .45058-002      .94981           11.879

          F,SIGDH,SIGDHD,E:   .12574-001      11.879           .69527          .30923-003
          PD,R,XRD,RMD:      -.47941-002      1.4991           .56708-001      .70318

STOP     999

@PRT R.IGDATA/NE.JL
FURPUR-27R3A       E36 SL74R1 04/15/80 14:14:09
```

```
LADSS*TRKLPTR(1).IGDATA/NEWJL
    1       LADSS PLATFORM INNER GIMBAL, UNIT STEP TIME RESPONSE
    2       K5     =        7.0
    3       K4     =        7.0
    4       TAU7   =        .025
    5       K3     =       46.66
    6       TAU2   =         .01
    7       TAU3   =       .0005
    8       TAU5   =         0.1
    9       TAU6   =         0.6
   10       PLIM   =        20.0
   11       A      =    100000.0
   12       KA     =       9.317
   13       RSG    =         1.0
   14       KT     =       12.75
   15       N      =        12.6
   16       JM     =       .0015
   17       JL     =        2.47
   18       KE     =        .141
   19       KTHD   =       .5595
   20       K2     =        14.0
   21       TAU4   =       .0015
   22       FT     =        .622
   23       DT     =       .0001
   24       DP     =         .01
   25       STOPT  =         1.0
   26       SINF   =         1.0
   27       SINA   =         1.0
   28       STPA   =         1.0
   29       SIGF   = FALSE

@XQT R.PROG
```

```
LADSS PLATFORM INNER GIMBAL, UNIT STEP TIME RESPONSE

      T R A C K   L O O P
      K5        7.0000
      K4        7.0000
      TAU7       .0250
      K3       46.6800
      TAU2       .0100
      TAU3       .0005
      TAU5       .1000
      TAU6       .3000
      PLIM      20.0000
      A     100000.00
      RA        9.3170
      RGH       1.0000
      KT       19.7500
      N        12.0000
      JA         .0015
      JL        2.4700
      KL         .1410
      KAHG       .5595
      K2       14.0000
      TAU4       .0015
      FF         62.0

      INTEGRATION INTERVAL =    .0000100

      RUN FOR  1.00 SECONDS, PRINT EVERY  .0100 SECONDS

      INPUT IS A STEP FUNCTION OF AMPLITUDE    1.0000

        TIME        - SIGD -        - EPS -       - SIGDH -       - XR -
      .1000-004     1.0000        .10000-004      .00000         .00000

                    - P -           - V -          - W -          - RM -
                    .00000         .00000         .00000         .00000

            F,SIGDH,SIGDHD,E:    1.0000        .00000         .00000        .00000
            PD,R,XRD,RMD:         .00000       .00000         .00000        .00000

        TIME        - SIGD -        - EPS -       - SIGDH -       - XR -
      .2000-004     1.0000        .20000-004      .16269-007     .00000

                    - P -           - V -          - W -          - RM -
                    .00000         .00000         .00000         .00000

            F,SIGDH,SIGDHD,E:    1.0000        .19600-006     .19600-001    .00000
            PD,R,XRD,RMD:         .00000       .00000         .00000        .00000

        TIME        - SIGD -        - EPS -       - SIGDH -       - XR -
      .3000-004     1.0000        .30000-004      .46859-007     .00000

                    - P -           - V -          - W -          - RM -
                 .45746-008        .00000         .00000         .00000

            F,SIGDH,SIGDHD,E:    1.0000        .58792-006     .39192-001    .19600-006
            PD,R,XRD,RMD:       .45746-003     .00000         .00000        .00000
```

```
   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .4000-004     1.0000       .40000-004    .10554-006    .97578-011

               - P -          - V -          - W -         - RM -
             .24376-007     .45742-003    .11564-005    .00000

        F,SIGDH,SIGDHD,E:    1.0000       .12736-005    .58776-001    .58792-006
        PD,R,XRD,RMD:       .13547-002    .42616-007    .42580-006    .00000

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .5000-004     1.0000       .50000-004    .17908-006    .51288-010

               - P -          - V -          - W -         - RM -
             .64118-007     .24375-007    .61621-005    .00000

        F,SIGDH,SIGDHD,E:    1.0000       .21549-005    .78349-001    .12736-005
        PD,R,XRD,RMD:       .28772-002    .22712-006    .22690-005    .00000

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .6000-004     1.0000       .60000-004    .26858-006    .13654-009

               - P -          - V -          - W -         - RM -
             .12214-006     .64112-007    .16207-004    .00000

        F,SIGDH,SIGDHD,E:    1.0000       .32316-005    .97914-001    .21549-005
        PD,R,XRD,RMD:       .47646-002    .59742-006    .59675-005    .00000

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .7000-004     1.0000       .70000-004    .37433-006    .28604-009

               - P -          - V -          - W -         - RM -
             .20598-006     .12213-006    .30875-004    .41870-015

        F,SIGDH,SIGDHD,E:    1.0000       .45045-005    .11747        .32318-005
        PD,R,XRD,RMD:       .70752-002    .11381-005    .11369-004    .18271-010

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .8000-004     1.0000       .80000-004    .49632-006    .52941-009

               - P -          - V -          - W -         - RM -
             .31781-006     .20596-006    .52066-004    .20902-014

        F,SIGDH,SIGDHD,E:    1.0000       .59722-005    .13702        .45043-005
        PD,R,XRD,RMD:       .97223-002    .19194-005    .19172-004    .92539-010

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .9000-004     1.0000       .90000-004    .63454-006    .88589-009

               - P -          - V -          - W -         - RM -
             .46135-006     .31776-006    .80335-004    .61429-014

        F,SIGDH,SIGDHD,E:    1.0000       .76355-005    .15656        .59722-005
        PD,R,XRD,RMD:       .12716-001    .29617-005    .29581-004    .26382-009

   TIME        - SIGD -       - EPS -       - SIGDH -      - XR -
 .1000-003     1.0000       .10000-003    .76900-006    .13987-008
```

	- P -	- V -	- W -	- RM -	
	.63972-006	.62130-006	.11662-003	.15121-013	
F,SIGDH,SIGDHD,E:		1.0000	.94940-005	.17609	.76355-005
PD,R,XRD,RMD:		.16042-001	.42996-005	.42941-004	.61553-009
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1000-001	1.0000	.99835-002	.71532-002	.55331-002	
	- P -	- V -	- W -	- RM -	
	.13224-001	.13209-001	5.3392	.21576-001	
F,SIGDH,SIGDHD,E:		.99448	.66074-001	16.112	.64413-001
PD,R,XRD,RMD:		1.3645	.13303	1.2263	7.6007
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2000-001	1.0000	.19646-001	.25279-001	.23857-001	
	- P -	- V -	- W -	- RM -	
	.25891-001	.25677-001	6.5416	.17517	
F,SIGDH,SIGDHD,E:		.97617	.30413	26.723	.12897
PD,R,XRD,RMD:		1.1391	.25411	2.4033	22.760
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.3000-001	1.0000	.29472-001	.50511-001	.52478-001	
	- P -	- V -	- W -	- RM -	
	.35016-001	.35005-001	8.8492	.46755	
F,SIGDH,SIGDHD,E:		.94755	.63780	33.447	.14027
PD,R,XRD,RMD:		.67831	.42079	3.2465	34.975
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4000-001	1.0000	.36776-001	.80123-001	.87369-001	
	- P -	- V -	- W -	- RM -	
	.39595-001	.39587-001	10.008	.85605	
F,SIGDH,SIGDHD,E:		.91267	.96413	37.432	.10612
PD,R,XRD,RMD:		.25626	.52645	3.6650	42.259
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5000-001	1.0000	.47716-001	.11221	.12467	
	- P -	- V -	- W -	- RM -	
	.40617-001	.40611-001	10.266	1.2974	
F,SIGDH,SIGDHD,E:		.87537	1.3502	39.515	.52835-001
PD,R,XRD,RMD:		-.24623-001	.60331	3.7518	44.952
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6000-001	1.0000	.55282-001	.14545	.16177	
	- P -	- V -	- W -	- RM -	
	.39595-001	.39590-001	10.008	1.7469	

```
            F,SIGDH,SIGDHD,E:    .85026        1.7502        40.307        .32573-002
            PD,R,XRD,RMD:       -.15701        .66576        3.6482        44.587

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .7000-001     1.0000        .64445-001    .17697          .19740

                - P -         - V -         - W -           - RM -
                .37805-001    .37800-001    9.5559          2.1843

            F,SIGDH,SIGDHD,E:    .80264        2.1535        40.251        -.30784-001
            PD,R,XRD,RMD:       -.13755        .70839        3.4735        42.768

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .8000-001     1.0000        .72340-001    .21220          .23124

                - P -         - V -         - W -           - RM -
                .36011-001    .36005-001    9.1021          2.6012

            F,SIGDH,SIGDHD,E:    .76279        2.5533        39.653        -.47801-001
            PD,R,XRD,RMD:       -.16685        .75274        3.2986        40.616

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .9000-001     1.0000        .77565-001    .24478          .26546

                - P -         - V -         - W -           - RM -
                .34503-001    .34497-001    8.7207          2.9973

            F,SIGDH,SIGDHD,E:    .73657        2.7454        38.720        -.51930-001
            PD,R,XRD,RMD:       -.13496        .79684        3.1508        38.681

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .1000+000     1.0000        .87074-001    .27649          .29434

                - P -         - V -         - W -           - RM -
                .33280-001    .33273-001    8.4114          3.3759

            F,SIGDH,SIGDHD,E:    .70569        3.3270        37.585        -.48863-001
            PD,R,XRD,RMD:       -.11175        .84116        3.0299        37.089

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .1100         1.0000        .93960-001    .30721          .32410

                - P -         - V -         - W -           - RM -
                .32224-001    .32217-001    8.1443          3.7599

            F,SIGDH,SIGDHD,E:    .67593        3.6967        36.336        -.43238-001
            PD,R,XRD,RMD:       -.10146        .88505        2.9247        35.752

    TIME        - SIGD -      - EPS -      - SIGDH -       - XR -
  .1200         1.0000        .10059        .33666          .35285

                - P -         - V -         - W -           - RM -
                .31219-001    .31211-001    7.8961          4.0912

            F,SIGDH,SIGDHD,E:    .64716        4.0535        35.027        -.37744-001
            PD,R,XRD,RMD:       -.10121        .92756        2.8245        34.529
```

TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1300	1.0000	.10695	.36542	.38358	
	- P -	- V -	- W -	- RM -	
	.30196-001	.30167-001	7.5314	4.4504	
	F,SIGDH,SIGDHD,E:	.51945	4.3971	33.694	-.33389-001
	PD,R,XRD,RMD:	-.10360	.96606	2.7229	33.318
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1400	1.0000	.11299	.39286	.40729	
	- P -	- V -	- W -	- RM -	
	.29140-001	.29131-001	7.3643	4.7574	
	F,SIGDH,SIGDHD,E:	.59274	4.7273	32.361	-.30123-001
	PD,R,XRD,RMD:	-.10715	1.0064	2.6184	32.076
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1500	1.0000	.11876	.41920	.43294	
	- P -	- V -	- W -	- RM -	
	.28064-001	.28055-001	7.0922	5.0718	
	F,SIGDH,SIGDHD,E:	.56709	5.0443	31.045	-.27539-001
	PD,R,XRD,RMD:	-.10777	1.0427	2.5123	30.806
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1600	1.0000	.12433	.44446	.45753	
	- P -	- V -	- W -	- RM -	
	.26993-001	.26985-001	6.8213	5.3734	
	F,SIGDH,SIGDHD,E:	.54249	5.3462	29.758	-.25232-001
	PD,R,XRD,RMD:	-.10624	1.0771	2.4069	29.532
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1700	1.0000	.12963	.46557	.48108	
	- P -	- V -	- W -	- RM -	
	.25947-001	.25937-001	6.5566	5.6624	
	F,SIGDH,SIGDHD,E:	.51894	5.6395	28.506	-.22972-001
	PD,R,XRD,RMD:	-.10251	1.1099	2.3042	28.280
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1800	1.0000	.13471	.49135	.50362	
	- P -	- V -	- W -	- RM -	
	.24940-001	.24930-001	6.3022	5.9591	
	F,SIGDH,SIGDHD,E:	.49640	5.9184	27.296	-.20694-001
	PD,R,XRD,RMD:	-.98555-001	1.1412	2.2053	27.066
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.1900	1.0000	.13956	.51404	.52519	

	- P -	- V -	- W -	- RM -	
	[illegible]-001	[illegible]-001	6.0595	6.2039	
F,SIGDH,SIGDHD,E:	.47455	6.1854	26.128	-.15427-001	
PD,R,XRD,RMD:	-.94117-001	1.1711	2.1109	25.905	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2000	1.0000	.14421	.53528	.54584	
	- P -	- V -	- W -	- RM -	
	.23053-001	.23049-001	5.8269	6.4573	
F,SIGDH,SIGDHD,E:	.45416	6.4410	25.005	-.16266-001	
PD,R,XRD,RMD:	-.39721-001	1.1599	2.0206	24.797	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2100	1.0000	.14665	.55560	.56561	
	- P -	- V -	- W -	- RM -	
	.22141-001	.22170-001	5.6045	6.6999	
F,SIGDH,SIGDHD,E:	.43441	6.6856	23.926	-.14269-001	
PD,R,XRD,RMD:	-.36072-001	1.2273	1.9342	23.736	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2200	1.0000	.15296	.57505	.58453	
	- P -	- V -	- W -	- RM -	
	.21559-001	.21527-001	5.3914	6.9321	
F,SIGDH,SIGDHD,E:	.41549	6.9196	22.891	-.12464-001	
PD,R,XRD,RMD:	-.82420-001	1.2536	1.8514	22.721	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2300	1.0000	.15696	.59366	.60264	
	- P -	- V -	- W -	- RM -	
	.20530-001	.20518-001	5.1870	7.1543	
F,SIGDH,SIGDHD,E:	.39736	7.1435	21.899	-.10851-001	
PD,R,XRD,RMD:	-.79116-001	1.2728	1.7719	21.747	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2400	1.0000	.16084	.61146	.61997	
	- P -	- V -	- W -	- RM -	
	.19754-001	.19742-001	4.9908	7.3671	
F,SIGDH,SIGDHD,E:	.38005	7.3576	20.948	-.94159-002	
PD,R,XRD,RMD:	-.76145-001	1.3028	1.6957	20.813	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.2500	1.0000	.16456	.62248	.63655	
	- P -	- V -	- W -	- RM -	
	.19010-001	.18997-001	4.8026	7.5706	

```
        F,SIGDH,SIGDHD,E:   .3[illegible]     7.[illegible]625      2[illegible].[illegible]47     -.[illegible]1375-002
        PD,R,XRD,RMD:      -.7[illegible]-[illegible]1   1.32[illegible]     1.5226     19.916

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .2[illegible]       1.0000       .16[illegible]11       .7[illegible]476        .65242

            - P -        - V -        - [illegible] -        - RM -
          .16296-001   .15283-001   4.[illegible]221       7.7654

        F,SIGDH,SIGDHD,E:   .3475[illegible]     7.75[illegible]      19.164     -.69948-002
        PD,R,XRD,RMD:      -.69[illegible]19-001   1.347[illegible]     1.5525     19.056

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .2[illegible]       1.0000       .17151       .66[illegible]54        .66761

            - P -        - V -        - [illegible] -        - RM -
          .17012-001   .1759[illegible]-001   4.4471       7.9518

        F,SIGDH,SIGDHD,E:   .53241     7.9453      16.329     -.59717-002
        PD,R,XRD,RMD:      -.66[illegible]-001   1.3632     1.4854     18.232

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .2[illegible]       1.0000       .17476       .67523        .68213

            - P -        - V -        - [illegible] -        - RM -
          .16956-001   .16742-001   4.2530       8.1301

        F,SIGDH,SIGDHD,E:   .31758     5.1250      17.530     -.50637-002
        PD,R,XRD,RMD:      -.64327-001   1.3689     1.4209     17.446

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .2700       1.0000       .17727       .68947        .69503

            - P -        - V -        - [illegible] -        - RM -
          .16325-001   .16315-001   4.1244       8.3007

        F,SIGDH,SIGDHD,E:   .3033[illegible]     8.2964      16.766     -.42481-002
        PD,R,XRD,RMD:      -.61750-001   1.4082     1.3593     16.688

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .3[illegible]       1.0000       .18[illegible]       .70309        .70932

            - P -        - V -        - [illegible] -        - RM -
          .15726-001   .15715-001   3.9727       8.4658

        F,SIGDH,SIGDHD,E:   .27070     8.4605      16.635     -.55117-002
        PD,R,XRD,RMD:      -.55345-001   1.4260     1.5004     15.965

 TIME       - SIGD -     - EPS -     - SIGDH -      - XR -
 .3100       1.0000       .16363       .71612        .72203

            - P -        - V -        - [illegible] -        - RM -
          .15154-001   .1514[illegible]-001   3.8274       8.6199

        F,SIGDH,SIGDHD,E:   .27778     6.6171      15.334     -.28566-002
        PD,R,XRD,RMD:      -.56353-001   1.4442     1.2440     15.273
```

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  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3200       1.0000          .1[illegible]   .72[illegible]   .73420

              - P -           - V -           - U -            - RM -
              .14[illegible]-001  .1457[illegible]-001  3.[illegible]  8.7[illegible]93

        F,SIGDH,SIGDHD,E:   .265[illegible]   [illegible].7670   14.665   -.22784-002
        PD,R,XRD,RMD:      -.5350[illegible]-001  1.[illegible]10   1.1900   14.610

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3300       1.0000          .13900          .74049           .74543

              - P -           - V -           - U -            - RM -
              .14077-001      .14063-001      3.5552           8.9121

        F,SIGDH,SIGDHD,E:   .2541[illegible]   8.9103   14.024   -.17705-002
        PD,R,XRD,RMD:      -.51506-001        1.4771   1.1363   13.976

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3400       1.0000          .17148          .75188           .75596

              - P -           - V -           - U -            - RM -
              .13573-001      .1355[illegible]-001  3.4277     9.6437

        F,SIGDH,SIGDHD,E:   .24305   9.0474   13.410   -.13236-002
        PD,R,XRD,RMD:      -.48055-001  1.4925   1.0688   13.369

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3500       1.0000          .17386          .76278           .76761

              - P -           - V -           - U -            - RM -
              .13091-001      .13076-001      3.3056           9.1794

        F,SIGDH,SIGDHD,E:   .23241   9.1785   12.624   -.93281-003
        PD,R,XRD,RMD:      -.47245-001  1.5072   1.0414   12.787

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3600       1.0000          .17613          .77319           .77779

              - P -           - V -           - U -            - RM -
              .12627-001      .12614-001      3.1988           9.3044

        F,SIGDH,SIGDHD,E:   .22222   9.3039   12.262   -.58589-003
        PD,R,XRD,RMD:      -.45376-001  1.5213   .99605   12.230

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3700       1.0000          .17830          .78316           .78752

              - P -           - V -           - U -            - RM -
              .12187-001      .12172-001      3.0770           9.4240

        F,SIGDH,SIGDHD,E:   .21249   9.4237   11.726   -.28765-003
        PD,R,XRD,RMD:      -.43472-001  1.5347   .95264   11.698

  TIME        - SIGD -        - EPS -         - SIGDH -        - XR -
  .3800       1.0000          .2003[illegible]  .79268         .79684
```

	- P -	- V -	- W -	- RM -	
	.11763-001	.11748-001	2.7697	9.5363	
F,SIGDH,SIGDHD,E:	.20317	9.5355	11.212	-.25511-004	
PD,R,XRD,RMD:	-.41455-001	1.5476	.71110	11.188	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.3900	1.0000	.20237	.80179	.80574	
	- P -	- V -	- W -	- RM -	
	.11356-001	.11343-001	2.6675	9.6477	
F,SIGDH,SIGDHD,E:	.19426	9.6479	10.721	.20289-003	
PD,R,XRD,RMD:	-.39430-001	1.5599	.87135	10.700	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4000	1.0000	.20426	.81049	.81426	
	- P -	- V -	- W -	- RM -	
	.10971-001	.10956-001	2.7696	9.7523	
F,SIGDH,SIGDHD,E:	.18575	9.7527	10.251	.40114-003	
PD,R,XRD,RMD:	-.37610-001	1.5716	.83333	10.233	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4100	1.0000	.20608	.81882	.82241	
	- P -	- V -	- W -	- RM -	
	.10600-001	.10585-001	2.6758	9.8523	
F,SIGDH,SIGDHD,E:	.17760	9.8529	9.8021	.57077-003	
PD,R,XRD,RMD:	-.36535-001	1.5829	.79694	9.7864	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4200	1.0000	.20782	.82678	.83020	
	- P -	- V -	- W -	- RM -	
	.10246-001	.10230-001	2.5861	9.9479	
F,SIGDH,SIGDHD,E:	.16961	9.9457	9.3724	.71561-003	
PD,R,XRD,RMD:	-.34935-001	1.5936	.76213	9.3593	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4300	1.0000	.20947	.83439	.83765	
	- P -	- V -	- W -	- RM -	
	.99062-002	.98905-002	2.5003	10.039	
F,SIGDH,SIGDHD,E:	.16236	10.040	8.9615	.63816-003	
PD,R,XRD,RMD:	-.33361-001	1.6039	.72882	8.9503	
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.4400	1.0000	.21106	.84167	.84477	
	- P -	- V -	- W -	- RM -	
	.95817-002	.95659-002	2.4183	10.127	

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        F,SIGDH,SIGDHD,E:    .15524        10.126     9.5686     .94199-003
        PD,R,XRD,RMD:      -.32755-001     1.6136     .69698     8.5591

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4500      1.0000          .21255        .84963         .85158

           - P -           - V -         - W -          - RM -
           .92712-002      .92553-002    2.3397         10.211

        F,SIGDH,SIGDHD,E:    .14642        10.212     8.1923     .10282-002
        PD,R,XRD,RMD:      -.30012-001     1.6232     .66650     8.1855

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4600      1.0000          .21403        .85528         .85810

           - P -           - V -         - W -          - RM -
           .89742-002      .89581-002    2.2646         10.291

        F,SIGDH,SIGDHD,E:    .14191        10.272     7.8334     .10985-002
        PD,R,XRD,RMD:      -.28312-001     1.6321     .63735     7.8277

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4700      1.0000          .21542        .86164         .86433

           - P -           - V -         - W -          - RM -
           .86899-002      .86736-002    2.1927         10.367

        F,SIGDH,SIGDHD,E:    .13568        10.368     7.4898     .11538-002
        PD,R,XRD,RMD:      -.27942-001     1.6407     .60945     7.4849

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4799      1.0000          .21674        .86772         .87028

           - P -           - V -         - W -          - RM -
           .84185-002      .84020-002    2.1240         10.440

        F,SIGDH,SIGDHD,E:    .12972        10.441     7.1612     .11982-002
        PD,R,XRD,RMD:      -.26593-001     1.6490     .58279     7.1574

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4899      1.0000          .21801        .87354         .87598

           - P -           - V -         - W -          - RM -
           .81582-002      .81419-002    2.0583         10.510

        F,SIGDH,SIGDHD,E:    .12403        10.511     6.8469     .12319-002
        PD,R,XRD,RMD:      -.26152-001     1.6566     .55727     6.8441

TIME       - SIGD -        - EPS -       - SIGDH -      - XR -
.4999      1.0000          .21922        .87910         .88142

           - P -           - V -         - W -          - RM -
           .79096-002      .78932-002    1.9954         10.577

        F,SIGDH,SIGDHD,E:    .11858        10.578     6.5464     .12560-002
        PD,R,XRD,RMD:      -.24962-001     1.6643     .53287     6.5446
```

TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5099	1.0000	.2203	.88441	.88563	
	- P -	- V -	- W -	- RM -	
	.76717-002	.76552-002	1.7252	10.641	
F,SIGDH,SIGDHD,E:		.11337	10.642	6.2591	.12717-002
PD,R,XRD,RMD:		-.23113-001	1.6715	.50953	6.2581
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5199	1.0000	.22149	.88949	.89161	
	- P -	- V -	- W -	- RM -	
	.74442-002	.74276-002	1.8777	10.702	
F,SIGDH,SIGDHD,E:		.10339	10.703	5.9844	.12801-002
PD,R,XRD,RMD:		-.21933-001	1.6784	.48720	5.9840
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5299	1.0000	.22255	.89435	.89637	
	- P -	- V -	- W -	- RM -	
	.72266-002	.72100-002	1.6227	10.760	
F,SIGDH,SIGDHD,E:		.10363	10.762	5.7216	.12822-002
PD,R,XRD,RMD:		-.21523-001	1.6649	.46585	5.7217
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5399	1.0000	.22356	.89900	.90092	
	- P -	- V -	- W -	- RM -	
	.70185-002	.70018-002	1.7701	10.816	
F,SIGDH,SIGDHD,E:		.99082-001	10.816	5.4704	.12786-002
PD,R,XRD,RMD:		-.20532-001	1.6912	.44543	5.4711
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5499	1.0000	.22453	.90344	.90527	
	- P -	- V -	- W -	- RM -	
	.68196-002	.68028-002	1.7198	10.870	
F,SIGDH,SIGDHD,E:		.94730-001	10.871	5.2303	.12710-002
PD,R,XRD,RMD:		-.19783-001	1.6972	.42591	5.2313
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5599	1.0000	.22545	.90768	.90944	
	- P -	- V -	- W -	- RM -	
	.66293-002	.66124-002	1.6716	10.921	
F,SIGDH,SIGDHD,E:		.90569-001	10.922	5.0006	.12593-002
PD,R,XRD,RMD:		-.18506-001	1.7029	.40724	5.0024
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5699	1.0000	.22634	.91174	.91341	

	- P -	- V -	- W -	- RM -	
	.64474-002	.64305-002	1.5256	10.970	
	F,SIGDH,SIGDHD,E:	.86570-001	10.971	4.7610	.12439-002
	PD,R,XRD,RMD:	-.17109-001	1.7084	.38939	4.7631
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5799	1.0000	.22718	.91562	.91722	
	- P -	- V -	- W -	- RM -	
	.62733-002	.62563-002	1.5816	11.016	
	F,SIGDH,SIGDHD,E:	.82786-001	11.018	4.5711	.12246-002
	PD,R,XRD,RMD:	-.16582-001	1.7137	.37231	4.5741
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5899	1.0000	.22799	.91953	.92086	
	- P -	- V -	- W -	- RM -	
	.61069-002	.60898-002	1.5395	11.061	
	F,SIGDH,SIGDHD,E:	.79149-001	11.062	4.3704	.12028-002
	PD,R,XRD,RMD:	-.16774-001	1.7187	.35598	4.3732
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.5999	1.0000	.22876	.92288	.92433	
	- P -	- V -	- W -	- RM -	
	.59477-002	.59306-002	1.4993	11.104	
	F,SIGDH,SIGDHD,E:	.75671-001	11.105	4.1785	.11792-002
	PD,R,XRD,RMD:	-.15670-001	1.7235	.34036	4.1814
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6099	1.0000	.22950	.92627	.92766	
	- P -	- V -	- W -	- RM -	
	.57955-002	.57784-002	1.4608	11.145	
	F,SIGDH,SIGDHD,E:	.72347-001	11.146	3.9949	.11545-002
	PD,R,XRD,RMD:	-.13916-001	1.7281	.32543	3.9984
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6199	1.0000	.23021	.92951	.93084	
	- P -	- V -	- W -	- RM -	
	.56498-002	.56327-002	1.4239	11.184	
	F,SIGDH,SIGDHD,E:	.69166-001	11.185	3.8195	.11276-002
	PD,R,XRD,RMD:	-.13872-001	1.7324	.31113	3.8224
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.6299	1.0000	.23088	.93261	.93387	
	- P -	- V -	- W -	- RM -	
	.55107-002	.54935-002	1.3688	11.221	

```
             F,SIGDH,SIGDHD,E:     .56127-001    11.224      3.6518      .11004-002
             PD,R,XRD,RMD:        -.12741-001    1.7366      .29743      3.6546
 ------------------------------------------------------------------------------
       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6399        1.0000          .23153         .93557      .93678

                   - P -           - V -         - W -        - RM -
                   .53780-002      .53606-002    1.3552       11.257
 ------------------------------------------------------------------------------
             F,SIGDH,SIGDHD,E:     .63624-001    11.256      3.4913      .10723-002
             PD,R,XRD,RMD:        -.13955-001    1.7406      .28446      3.4941
 ------------------------------------------------------------------------------
       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6499        1.0000          .23215         .93840      .93956
 ------------------------------------------------------------------------------
                   - P -           - V -         - W -        - RM -
                   .52509-002      .52335-002    1.3230       11.291

             F,SIGDH,SIGDHD,E:     .60446-001    11.292      3.3380      .10448-002
             PD,R,XRD,RMD:        -.11063-001    1.7445      .27198      3.3411
 ------------------------------------------------------------------------------
       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6599        1.0000          .23274         .94111      .94221

                   - P -           - V -         - W -        - RM -
                   .51289-002      .51116-002    1.2922       11.323
 ------------------------------------------------------------------------------
             F,SIGDH,SIGDHD,E:     .57790-001    11.324      3.1914      .10132-002
             PD,R,XRD,RMD:        -.13633-001    1.7431      .26002      3.1945
 ------------------------------------------------------------------------------
       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6699        1.0000          .23330         .94370      .94475
 ------------------------------------------------------------------------------
                   - P -           - V -         - W -        - RM -
                   .50129-002      .49955-002    1.2629       11.355

             F,SIGDH,SIGDHD,E:     .55251-001    11.356      3.0513      .98503-003
             PD,R,XRD,RMD:        -.10916-001    1.7516      .24864      3.0546
 ------------------------------------------------------------------------------
       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6799        1.0000          .23384         .94617      .94718

                   - P -           - V -         - W -        - RM -
                   .49014-002      .48640-002    1.2347       11.384
 ------------------------------------------------------------------------------
             F,SIGDH,SIGDHD,E:     .52623-001    11.385      2.9173      .95356-003
             PD,R,XRD,RMD:        -.13111-001    1.7550      .23770      2.9203

       TIME        - SIGD -        - EPS -      - SIGDH -     - XR -
      .6899        1.0000          .23436         .94854      .94950
 ------------------------------------------------------------------------------
                   - P -           - V -         - W -        - RM -
                   .47954-002      .47777-002    1.2078       11.413

             F,SIGDH,SIGDHD,E:     .50505-001    11.414      2.7892      .92554-003
             PD,R,XRD,RMD:        -.96557-002    1.7582      .22729      2.7928
 ------------------------------------------------------------------------------
```

```
 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .6999       1.0000        .23485        .95050          .95172

             - P -         - V -         - W -           - RM -
             .46933-002    .46758-002    1.1820          11.440

     F,SIGDH,SIGDHD,E:    .48284-001    11.441        2.6067        .89407-003
     PD,R,XRD,WMD:        -.12050-001   1.7612        .21725        2.6698

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7099       1.0000        .23532        .95296          .95384

             - P -         - V -         - W -           - RM -
             .45965-002    .45790-002    1.1576          11.466

     F,SIGDH,SIGDHD,E:    .46163-001    11.467        2.5496        .86606-003
     PD,R,XRD,WMD:        -.10882-001   1.7641        .20778        2.5530

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7199       1.0000        .23577        .95503          .95587

             - P -         - V -         - W -           - RM -
             .45029-002    .44854-002    1.1339          11.491

     F,SIGDH,SIGDHD,E:    .44135-001    11.492        2.4377        .83673-003
     PD,R,XRD,WMD:        -.87151-002   1.7667        .19860        2.4414

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7299       1.0000        .23620        .95701          .95781

             - P -         - V -         - W -           - RM -
             .44140-002    .43964-002    1.1114          11.515

     F,SIGDH,SIGDHD,E:    .42197-001    11.516        2.3307        .80612-003
     PD,R,XRD,WMD:        -.95311-002   1.7696        .18987        2.3342

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7399       1.0000        .23661        .95889          .95966

             - P -         - V -         - W -           - RM -
             .43298-002    .43122-002    1.0901          11.538

     F,SIGDH,SIGDHD,E:    .40345-001    11.538        2.2265        .78106-003
     PD,R,XRD,WMD:        -.90145-002   1.7722        .18161        2.2321

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7499       1.0000        .23701        .96070          .96143

             - P -         - V -         - W -           - RM -
             .42479-002    .42303-002    1.0694          11.559

     F,SIGDH,SIGDHD,E:    .38571-001    11.560        2.1306        .75209-003
     PD,R,XRD,WMD:        -.10042-001   1.7746        .17358        2.1333

 TIME        - SIGD -      - EPS -       - SIGDH -       - XR -
 .7599       1.0000        .23738        .96243          .96312
```

	- P -	- V -	- W -	- RM -	
	.41708-002	.41331-002	1.0499	11.580	
F,SIGDH,SIGDHD,E:		.36377-001	11.581	2.0370	.72596-003
PD,R,XRD,RMD:		-.97472-002	1.7769	.15601	2.0405
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7699	1.0000	.23774	.96405	.96474	
	- P -	- V -	- W -	- RM -	
	.40960-002	.40783-002	1.0310	11.600	
F,SIGDH,SIGDHD,E:		.35256-001	11.601	1.9476	.70012-003
PD,R,XRD,RMD:		-.60756-002	1.7792	.15667	1.9506
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7799	1.0000	.23809	.96565	.96629	
	- P -	- V -	- W -	- RM -	
	.40253-002	.40076-002	1.0131	11.619	
F,SIGDH,SIGDHD,E:		.33710-001	11.620	1.8622	.67496-003
PD,R,XRD,RMD:		-.55105-002	1.7813	.15174	1.8649
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7899	1.0000	.23842	.96716	.96777	
	- P -	- V -	- W -	- RM -	
	.39571-002	.39394-002	.99567	11.637	
F,SIGDH,SIGDHD,E:		.32236-001	11.638	1.7805	.64945-003
PD,R,XRD,RMD:		-.52973-002	1.7835	.14505	1.7829
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.7999	1.0000	.23873	.96860	.96919	
	- P -	- V -	- W -	- RM -	
	.38924-002	.38747-002	.97952	11.655	
F,SIGDH,SIGDHD,E:		.30815-001	11.655	1.7023	.62430-003
PD,R,XRD,RMD:		-.95562-002	1.7853	.13670	1.7045
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.8099	1.0000	.23903	.96998	.97054	
	- P -	- V -	- W -	- RM -	
	.38303-002	.38125-002	.96380	11.671	
F,SIGDH,SIGDHD,E:		.29462-001	11.672	1.6277	.60213-003
PD,R,XRD,RMD:		-.52005-002	1.7871	.13260	1.6305
TIME	- SIGD -	- EPS -	- SIGDH -	- XR -	
.8199	1.0000	.23932	.97130	.97183	
	- P -	- V -	- W -	- RM -	
	.37709-002	.37531-002	.94878	11.687	

```
       F,SIGDH,SIGDHD,E:     .25169-001    11.689       1.5565       .57856-003
       PD,R,XRD,RMD:        -.44532-002    1.7587       .12678       1.5594

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.3299        1.0000          .23959        .97256         .97307

             - P -           - V -         - W -          - RM -
             .37143-002      .35755-002    .93447         11.702

       F,SIGDH,SIGDHD,E:     .26933-001    11.705       1.4830       .55456-003
       PD,R,XRD,RMD:        -.73316-002    1.7906       .12123       1.4900

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.4399        1.0000          .23985        .97376         .97425

             - P -           - V -         - W -          - RM -
             .36601-002      .36422-002    .92075         11.717

       F,SIGDH,SIGDHD,E:     .25751-001    11.717       1.4228       .53465-003
       PD,R,XRD,RMD:        -.39017-002    1.7923       .11591       1.4267

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.6499        1.0000          .24011        .97492         .97538

             - P -           - V -         - W -          - RM -
             .36090-002      .35911-002    .96764         11.731

       F,SIGDH,SIGDHD,E:     .24621-001    11.731       1.3603       .51463-003
       PD,R,XRD,RMD:        -.42252-002    1.7938       .11089       1.3627

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.6599        1.0000          .24035        .97602         .97646

             - P -           - V -         - W -          - RM -
             .35569-002      .35416-002    .89517         11.744

       F,SIGDH,SIGDHD,E:     .23541-001    11.744       1.3007       .49317-003
       PD,R,XRD,RMD:        -.35507-002    1.7953       .10598       1.3036

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.6699        1.0000          .24057        .97707         .97749

             - P -           - V -         - W -          - RM -
             .35119-002      .34940-002    .86328         11.757

       F,SIGDH,SIGDHD,E:     .22538-001    11.757       1.2436       .47457-003
       PD,R,XRD,RMD:        -.37774-002    1.7967       .10136       1.2481

TIME         - SIGD -        - EPS -       - SIGDH -      - XR -
.6799        1.0000          .24079        .97807         .97848

             - P -           - V -         - W -          - RM -
             .34651-002      .34472-002    .87146         11.769

       F,SIGDH,SIGDHD,E:     .21521-001    11.769       1.1892       .45288-003
       PD,R,XRD,RMD:        -.83157-002    1.7981       .96787-001   1.1919
```

```
TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.3699       1.0000        .24100        .97704         .97742

            - P -         - V -         - W -          - RM -
            .34623-002    .34046-002    .30074         11.760

        F,SIGDH,SIGDHD,E:   .20576-001    11.731    1.1372        .43607-003
        PD,R,XRD,RMD:      -.31036-002    1.7794    .92622-001    1.1409

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.5399       1.0000        .24120        .97995         .98033

            - P -         - V -         - W -          - RM -
            .33824-002    .33644-002    .85052         11.791

        F,SIGDH,SIGDHD,E:   .19676-001    11.792    1.0573        .42176-003
        PD,R,XRD,RMD:      -.35609-002    1.6006    .88651-001    1.0925

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.7099       1.0000        .25140        .96083         .98119

            - P -         - V -         - W -          - RM -
            .33425-002    .33245-002    .84042         11.802

        F,SIGDH,SIGDHD,E:   .13015-001    11.802    1.0398        .40448-003
        PD,R,XRD,RMD:      -.29426-002    1.5016    .84738-001    1.0448

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.7199       1.0000        .24153        .95167         .98201

            - P -         - V -         - W -          - RM -
            .33040-002    .32863-002    .83069         11.812

        F,SIGDH,SIGDHD,E:   .17959-001    11.312    .99422        .38564-003
        PD,R,XRD,RMD:      -.23826-002    1.6029    .80965-001    1.0004

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.9299       1.0000        .24175        .96248         .98280

            - P -         - V -         - W -          - RM -
            .32667-002    .32487-002    .32128         11.822

        F,SIGDH,SIGDHD,E:   .17201-001    11.322    .95036        .36812-003
        PD,R,XRD,RMD:      -.39547-002    1.6040    .77518-001    .95352

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.7399       1.0000        .24192        .93324         .98355

            - P -         - V -         - W -          - RM -
            .32338-002    .32157-002    .31294         11.831

        F,SIGDH,SIGDHD,E:   .16447-001    11.631    .90909        .35489-003
        PD,R,XRD,RMD:      -.26923-002    1.6351    .74075-001    .91489

TIME        - SIGD -      - EPS -       - SIGDH -      - XR -
.9499       1.0000        .24206        .93398         .98427
```

```
            - P -          - V -          - W -          - RM -
          .32004-002     .31124-002     .80452         11.840

      F,SIGDH,SIGDHD,E:   .15727-001     11.840         .86922         .33903-003
      PD,R,XRD,RMD:      -.74925-002     1.8061         .70809-001     .87214

   TIME       - SIGD -       - EPS -        - SIGDH -       - XR -
  .9599        1.0000         .24223         .95408          .98496

            - P -          - V -          - W -          - RM -
          .31666-002     .31450-002     .79596         11.848

      F,SIGDH,SIGDHD,E:   .15030-001     11.849         .83132         .32246-003
      PD,R,XRD,RMD:      -.33417-002     1.8070         .67501-001     .83431

   TIME       - SIGD -       - EPS -        - SIGDH -       - XR -
  .9699        1.0000         .24234         .96535          .98562

            - P -          - V -          - W -          - RM -
          .31303-002     .31162-002     .78829         11.856

      F,SIGDH,SIGDHD,E:   .14380-001     11.857         .79502         .30863-003
      PD,R,XRD,RMD:      -.16390-002     1.8079         .64526-001     .79654

   TIME       - SIGD -       - EPS -        - SIGDH -       - XR -
  .9799        1.0000         .24252         .96599          .98625

            - P -          - V -          - W -          - RM -
          .31073-002     .30893-002     .78097         11.864

      F,SIGDH,SIGDHD,E:   .13751-001     11.864         .76026         .29600-003
      PD,R,XRD,RMD:      -.36569-002     1.8086         .61686-001     .76278

   TIME       - SIGD -       - EPS -        - SIGDH -       - XR -
  .9899        1.0000         .24265         .96660          .98685

            - P -          - V -          - W -          - RM -
          .30926-002     .30645-002     .77478         11.872

      F,SIGDH,SIGDHD,E:   .13149-001     11.872         .72686         .29087-003
      PD,R,XRD,RMD:      -.48204-002     1.8096         .59268-001     .73163

   TIME       - SIGD -       - EPS -        - SIGDH -       - XR -
  .9999        1.0000         .24278         .96719          .98743

            - P -          - V -          - W -          - RM -
          .30568-002     .30387-002     .76816         11.879

      F,SIGDH,SIGDHD,E:   .12574-001     11.879         .69529         .28086-003
      PD,R,XRD,RMD:      -.24074-002     1.8104         .56705-001     .70318

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